

HUMAN AMINOACYL-tRNA SYNTHETASE POLYPEPTIDES  
USEFUL FOR THE REGULATION OF ANGIOGENESIS

GOVERNMENTAL RIGHTS

5        This invention was made with governmental support from the United States Government, National Institutes of Health, Grant GM23562; the United States Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

10      1. Field of the Invention

The invention relates to compositions comprising truncated tRNA synthetase polypeptides, as well as nucleic acids encoding such truncated tRNA synthetase polypeptides. Methods of making and using such compositions are also disclosed.

15      2. Background of the Invention

Aminoacyl-tRNA synthetases, which catalyze the aminoacylation of tRNA molecules, are ancient proteins that are essential for decoding genetic information during the process of translation. In higher eukaryotes, nine aminoacyl-tRNA synthetases associate with at least three other polypeptides to form a supramolecular multienzyme complex (Mirande *et al.*, 1985, *Eur. J. Biochem.* 147:281-89). Each of the eukaryotic tRNA synthetases consists of a core enzyme, which is closely related to the prokaryotic counterpart of the tRNA synthetase, and an additional domain that is appended to the amino-terminal or carboxyl-terminal end of the core enzyme (Mirande, 1991, *Prog. Nucleic Acid Res. Mol. Biol.* 40:95-142). Human tyrosyl-tRNA synthetase (TyrRS), for example, has a carboxyl-terminal domain that is not part of prokaryotic and lower eukaryotic TyrRS molecules (Figure 1) (Rho *et al.*, 1998, *J. Biol. Chem.* 273:11267-73). It has also been suggested that both the bovine and rabbit TyrRS molecules possess an extra domain (Kleeman *et al.*, 1997, *J. Biol. Chem.* 272:14420-25).

In most cases, the appended domains appear to contribute to the assembly of the multienzyme complex (Mirande, *supra*). However, the presence of an extra

domain is not strictly correlated with the association of a synthetase into the multienzyme complex. Higher eukaryotic TyrRS, for example, is not a component of the multienzyme complex (Mirande *et al.*, *supra*).

5 The carboxyl-terminal domain of human TyrRS shares a 51% sequence identity with the mature form of human endothelial monocyte-activating polypeptide II (EMAP II) (Rho *et al.*, *supra*). TyrRS is the only higher eukaryotic aminoacyl-tRNA synthetase known to contain an EMAP II-like domain. The EMAP-like domain of TyrRS has been shown to be dispensable for 10 aminoacylation *in vitro* and in yeast (Wakasugi *et al.*, 1998, *EMBO J.* 17:297-305).

15 EMAP II is a proinflammatory cytokine that was initially identified as a product of murine methylcholanthrene A-induced fibrosarcoma cells. Pro-EMAP II is cleaved and is secreted from apoptotic cells to produce a biologically active 22-kD mature cytokine (Kao, *et al.*, 1994, *J. Biol. Chem.* 269:25106-19). The mature EMAP II can induce migration of mononuclear phagocytes (MPs) and polymorphonuclear leukocytes (PMNs); it also stimulates the production of tumor necrosis factor- $\alpha$  (TNF $\alpha$ ) and tissue factor by MPs and the release of myeloperoxidase from PMNs.

20 The catalytic core domain of tryptophanyl-tRNA synthetase (TrpRS) is a close homolog of the catalytic domain of TyrRS (Brown *et al.*, 1997, *J. Mol. Evol.* 45:9-12). As shown in Figure 15, mammalian TrpRS molecules have an amino-terminal appended domain. In normal human cells, two forms of TrpRS can be detected: a major form consisting of the full-length molecule and a minor 25 truncated form ("mini TrpRS"). The minor form is generated by the deletion of the amino-terminal domain through alternative splicing of the pre-mRNA (Tolstrup *et al.*, 1995, *J. Biol. Chem.* 270:397-403). The amino-terminus of mini TrpRS has been determined to be the met residue at position 48 of the full-length TrpRS molecule (*id.*). Alternatively, truncated TrpRS may be generated by 30 proteolysis (Lemaire *et al.*, 1975, *Eur. J. Biochem.* 51:237-52). For example, bovine TrpRS is highly expressed in the pancreas and is secreted into the pancreatic juice (Kisselev, 1993, *Biochimie* 75:1027-39), thus resulting in the

production of a truncated TrpRS molecule. These results suggest that truncated TrpRS has a function other than the aminoacylation of tRNA (Kisselev, *supra*).

Angiogenesis, or the proliferation of new capillaries from pre-existing blood vessels, is a fundamental process necessary for embryonic development, subsequent growth, and tissue repair. Angiogenesis is a prerequisite for the development and differentiation of the vascular tree, as well as for a wide variety of fundamental physiological processes including embryogenesis, somatic growth, tissue and organ repair and regeneration, cyclical growth of the corpus luteum and endometrium, and development and differentiation of the nervous system. In the female reproductive system, angiogenesis occurs in the follicle during its development, in the corpus luteum following ovulation and in the placenta to establish and maintain pregnancy. Angiogenesis additionally occurs as part of the body's repair processes, e.g. in the healing of wounds and fractures. Angiogenesis is also a factor in tumor growth, since a tumor must continuously stimulate growth of new capillary blood vessels in order to grow. Angiogenesis is an essential part of the growth of human solid cancer, and abnormal angiogenesis is associated with other diseases such as rheumatoid arthritis, psoriasis, and diabetic retinopathy (Folkman, J. and Klagsbrun, M., *Science* 235:442-447, (1987)).

Several factors are involved in angiogenesis. Both acidic and basic fibroblast growth factor molecules that are mitogens for endothelial cells and other cell types. Angiotropin and angiogenin can induce angiogenesis, although their functions are unclear (Folkman, J., 1993, *Cancer Medicine* pp. 153-170, Lea and Febiger Press). A highly selective mitogen for vascular endothelial cells is vascular endothelial growth factor or VEGF (Ferrara, N., et al., *Endocr. Rev.* 13:19-32, (1992)).

## SUMMARY OF THE INVENTION

The invention provides novel truncated tRNA synthetase polypeptides having chemokine activity that are useful for research, diagnostic, prognostic and therapeutic applications. In one embodiment, the tRNA synthetase polypeptides

are useful for regulating vascular endothelial cell function, and in particular, for regulating angiogenesis.

5 The truncated tryptophanyl tRNA synthetase derived polypeptides have an amino-terminal truncation but may include a Rossmann fold nucleotide binding domain. The isolated polypeptide is capable of regulating vascular endothelial cell function and preferably has a size of at least about 46 kiloDaltons (kD).

10 Preferred truncated tryptophanyl tRNA synthetase polypeptides include a polypeptide consisting essentially of amino acid residues 48-471 of SEQ ID NO:9; a polypeptide consisting essentially of amino acid residues 71-471 of SEQ ID NO:9; a polypeptide of approximately 47 kD molecular weight produced by cleavage of the polypeptide of SEQ ID NO:9 with polymorphonuclear leucocyte elastase; and fragments thereof comprising the amino acid sequence -Asp-Leu-Thr-. In one preferred embodiment, the truncated tRNA synthetase polypeptide is mammalian, and more preferably, human.

15 In another embodiment, the invention comprises an isolated nucleic acid molecule comprising a polynucleotide having a nucleotide sequence at least 95% identical to a sequence selected from the group consisting of a polynucleotide of SEQ ID NO:9, a polynucleotide which is hybridizable to a polynucleotide of SEQ ID NO:9, a polynucleotide encoding a truncated tryptophanyl-tRNA synthetase polypeptide which includes a Rossmann fold nucleotide binding domain, a 20 polynucleotide that is hybridizable to a polynucleotide encoding a truncated tryptophanyl-tRNA synthetase polypeptide which includes a Rossmann fold nucleotide binding domain, a polynucleotide encoding a polypeptide mentioned in the preceding paragraph, a polynucleotide that is hybridizable to a polynucleotide encoding a polypeptide mentioned in the preceding paragraph, a polynucleotide that is hybridizable to a polynucleotide encoding a polypeptide epitope of SEQ ID NO:9, and a polynucleotide that is hybridizable to a polynucleotide encoding a polypeptide epitope of SEQ ID NO:9. In a preferred embodiment the invention comprises a recombinant expression vector comprising the isolated nucleic acid molecule of encoding a tRNA synthetase polypeptide. Another embodiment is a host cell comprising a recombinant expression vector comprising the isolated nucleic acid molecule of SEQ ID NO:9 encoding a tRNA synthetase polypeptide.

In one embodiment, the present invention is a process for making tRNA synthetase polypeptides by treating tryptophanyl-tRNA synthetase with a protease. One preferred protease is polymorphonuclear leukocyte elastase.

The invention provides compositions comprising tryptophanyl-tRNA synthetase polypeptides and a pharmaceutically suitable excipient. Such compositions are suitable for transdermal, transmucosal, enteral or parenteral administration. In another embodiment, the tRNA synthetase polypeptide can be used for the preparation of a pharmaceutical composition for transdermal, transmucosal, enteral or parenteral administration.

In one embodiment, the tRNA synthetase polypeptide can have angiogenic activity at least two-fold greater than control levels. In embodiments in which the tRNA synthetase polypeptide has angiostatic activity, the polypeptide suppresses at least ten percent of angiogenic activity, more preferably at least ninety percent of angiogenic activity.

The invention further provides a method of enhancing angiogenesis in a mammal comprising the step of administering an angiogenically effective amount of a composition comprising an angiogenic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

The invention further provides a method of suppressing angiogenesis in a mammal comprising the step of administering an angiostatically effective amount of a composition comprising an angiostatic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

In another embodiment, the invention provides a method of enhancing angiogenesis to a graft in a mammal comprising the step of administering an angiogenically effective amount of a composition comprising an angiogenic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

In another embodiment, the invention provides a method of treating myocardial infarction in a mammal comprising the step of administering an angiogenically effective amount of a composition comprising an angiogenic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

In another embodiment, the invention provides a method of treating a condition that would benefit from increased angiogenesis in a mammal

comprising the step of administering an angiogenically effective amount of a composition comprising an angiogenic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

5 In another embodiment, the invention provides a method of treating a condition that would benefit from decreased angiogenesis in a mammal comprising the step of administering an angiostatically effective amount of the composition comprising an angiostatic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

10 In another embodiment, the invention provides a method of treating a solid tumor in a mammal comprising the step of administering an angiostatically effective amount of the composition comprising an angiostatic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

15 In another embodiment, the invention provides a method of suppressing tumor metastasis in a mammal comprising the step of administering an angiostatically effective amount of the composition comprising an angiostatic tRNA synthetase polypeptide and a pharmaceutically suitable excipient.

## **DESCRIPTION OF THE DRAWINGS**

20 Figure 1 illustrates a schematic alignment of *E. coli* TyrRS, human full-length TyrRS, human mini TyrRS, the human TyrRS carboxyl-terminal domain, and human mature EMAP II;

25 Figure 2 illustrates the effects of human full-length TyrRS, human mini TyrRS, the human TyrRS carboxyl-terminal domain, human mature EMAP II, and *E. coli* TyrRS on MP chemotaxis (white bars) and MP TNF $\alpha$  production (gray bars);

Figure 3 illustrates the effects of human full-length TyrRS, human mini TyrRS, the human TyrRS carboxyl-terminal domain, human mature EMAP II, and *E. coli* TyrRS on MP tissue factor production (white bars) and PMN release of myeloperoxidase (gray bars);

30 Figure 4 illustrates the effects of human full-length TyrRS, human mini TyrRS, the human TyrRS carboxyl-terminal domain, human mature EMAP II, *E. coli* TyrRS, human TyrRS mutant, and IL-8 on PMN chemotaxis;

Figure 5 illustrates a schematic partial alignment of human mini TyrRS (SEQ ID NO: 17), *E. coli* TyrRS (SEQ ID NO: 18), IL-8 (SEQ ID NO: 19), Gro $\alpha$  (SEQ ID NO: 20), and NAP-2 (SEQ ID NO: 21); the connective polypeptide 1 (CP1) which splits the Rossmann nucleotide-binding fold in TyrRS is indicated;

5 Figure 6 illustrates the results of competition assays in which unlabeled human mini TyrRS, human TyrRS mutant, human full-length TyrRS, the human TyrRS carboxyl-terminal domain, human mature EMAP II, *E. coli* TyrRS, IL-8, Gro $\alpha$ , or NAP-2 was used in molar excess with  $^{125}\text{I}$ -human mini TyrRS on PMNs;

10 Figures 7A-7B illustrate the results of immunoblot analysis of (A) supernatants following growth of U-937 cells in normal media (Lane 1) and serum-free media (Lane 2), and (B) supernatants following growth of U-937 cells in serum-free media for 4, 12, or 24 hours (Lanes 1-3), or from a cell extract isolated from U-937 cells grown in serum-free media for 24 hours;

15 Figures 8A-8B illustrate (A) the results of immunoblot analysis of human full-length TyrRS (Lane 1), human mini TyrRS (Lane 2), the TyrRS carboxyl-terminal domain (Lane 3), the extended carboxyl-terminal domain of human TyrRS (Lane 4), and human full-length TyrRS following cleavage with PMN elastase (Lane 5), and (B) a schematic representation of the cleavage sites for human pro-EMAP II (SEQ ID NO: 22) and human full-length TyrRS (SEQ ID NO: 23);

20 Figure 9 illustrates a schematic alignment of human full-length TyrRS, human mini TyrRS, *S. cerevisiae* TyrRS, and *E. coli* TyrRS;

25 Figure 10 illustrates the results of competition assays in which unlabeled human mini TyrRS, *S. cerevisiae* TyrRS, or *E. coli* TyrRS was used in molar excess with  $^{125}\text{I}$ -human mini TyrRS on PMNs;

Figure 11 illustrates the effects of human mini TyrRS, *S. cerevisiae* TyrRS, or *E. coli* TyrRS on PMN chemotaxis;

30 Figure 12 illustrates a schematic alignment of the human EMAP II-like domains and corresponding synthetic peptides for human full-length TyrRS (SEQ ID NO: 24), human EMAP II (SEQ ID NO: 25-26), *C. elegans* MetRS (SEQ ID NO: 27), and *S. cerevisiae* Arc1p (SEQ ID NO: 28);

Figure 13 illustrates the effects of synthetic peptides derived from human TyrRS, human EMAP II, *C. elegans* MetRS, and *S. cervisiae* Arc1p on PMN chemotaxis

5 Figure 14 illustrates a schematic comparison between human mini TyrRS and  $\alpha$ -chemokines (the carboxyl-terminal portions of each have been omitted); the location of  $\beta$ -sheets (solid arrows) and ELR motifs (circles) are indicated;

Figure 15 illustrates a schematic alignment of human full-length TyrRS, human mini TyrRS, human full-length TrpRS, and human mini TrpRS; the carboxyl-terminal and amino-terminal appended domains (hatched) are indicated;

10 Figure 16 illustrates the angiogenic activity of human full-length TyrRS, human mini TyrRS, human mini TyrRS mutant, or human VEGF on HUVEC chemotaxis;

15 Figure 17 illustrates the angiogenic activity of human full-length TyrRS, human mini TyrRS, human mini TyrRS mutant, human mini TyrRS + IP-10, human VEGF, or human VEGF + IP-10 on the CAMs of 10-day-old chick embryos;

Figure 18 illustrates the angiogenic activity of human full-length TyrRS or human mini TyrRS on endothelial cell proliferation;

20 Figure 19 illustrates the effect of human full-length TrpRS or human mini TrpRS on human VEGF-induced or human mini TyrRS-induced endothelial migration;

Figure 20 illustrates the effect of human full-length TrpRS or human mini TrpRS on the angiogenic activity of human VEGF or human mini TyrRS on chick CAM;

25 Figure 21 illustrates the results of immunoblot analysis showing the secretion of human TrpRS from human U-937 cells;

Figure 22 illustrates the cleavage of human full-length TrpRS by PMN elastase; TrpRS was exposed to PMN elastase for 0 minutes (Lane 1), 15 minutes (Lane 2), 30 minutes (Lane 3), or 60 minutes (Lane 4);

30 Figure 23 illustrates the effect of human supermini TrpRS on the angiogenic activity of human VEGF or human mini TyrRS on chick CAM;

Figure 24 illustrates the amino acid sequence similarity of human TrpRS (SEQ ID NO: 45 and SEQ ID NO: 51), bovine TrpRS (SEQ ID NO: 46 and SEQ ID NO: 52), mouse TrpRS (SEQ ID NO: 47 and SEQ ID NO: 53), rabbit TrpRS (SEQ ID NO: 48 and SEQ ID NO: 54), human semaphorin-E (SEQ ID NO: 49), mouse semaphorin-E (SEQ ID NO: 50), and mouse neuropilin-2 (SEQ ID NO: 55); the amino-terminal residue of the mini, supermini, and inactive forms of TrpRS (arrows), identical residues (asterisks), semi-conserved residues (dots), and insertions in the c-domain of neuropilin-2 (bars) are indicated;

Figure 25 illustrates the regions of semaphorin-E and neuropilin-2 that share sequence similarity with mammalian TrpRS (indicated by arrows); semaphorin-E and neuropilin-2 domains are indicated as follows: semaphorin domain (sema), immunoglobulin domain (Ig), carboxy-terminal basic domain (C), complement-binding domain (a1, a2), coagulation factor domain (b1, b2), c domain (c), transmembrane domain (TM), and cytoplasmic domain (Cy). Isoforms of neuropilin exist with insertions of 5, 17, or 22 amino acids in the c-domain.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

### Definitions

"Truncated tRNA synthetase polypeptides" means polypeptides that are shorter than the corresponding full length tRNA synthetase.

"TrpRS" means tryptophanyl-tRNA synthetase.

"TyrRS" means tyrosyl-tRNA synthetase.

"Cell culture" encompasses both the culture medium and the cultured cells.

The phrase "isolating a polypeptide from the cell culture" encompasses isolating a soluble or secreted polypeptide from the culture medium as well as isolating an integral membrane protein from the cultured cells.

"Cell extract" includes culture media, especially spent culture media from which the cells have been removed. A cell extract that contains the DNA or protein of interest should be understood to mean a homogenate preparation or cell-free preparation obtained from cells that express the protein or contain the DNA of interest.

"Plasmid" is an autonomous, self-replicating extrachromosomal DNA molecule and is designated by a lower case "p" preceded and/or followed by capital letters and/or numbers. The starting plasmids herein are either commercially available, publicly available on an unrestricted basis, or can be 5 constructed from available plasmids in accord with published procedures. In addition, equivalent plasmids to those described are known in the art and will be apparent to the ordinarily skilled artisan.

"Digestion" of DNA refers to catalytic cleavage of the DNA with a restriction enzyme that acts only at certain sequences in the DNA. The various 10 restriction enzymes used herein are commercially available and their reaction conditions, cofactors and other requirements were used as would be known to the ordinarily skilled artisan. For analytical purposes, typically 1  $\mu$ g of plasmid or DNA fragment is used with about 2 units of enzyme in about 20  $\mu$ l of buffer solution. For the purpose of isolating DNA fragments for plasmid construction, 15 typically 5 to 50  $\mu$ g of DNA are digested with 20 to 250 units of enzyme in a larger volume. Appropriate buffers and substrate amounts for particular restriction enzymes are specified by the manufacturer. Incubation times of about 1 hour at 37 degrees C. are ordinarily used, but may vary in accordance with the supplier's instructions. After digestion the reaction is electrophoresed directly on 20 a poly-acrylamide gel to isolate the desired fragment. The nucleotides present in various DNA and RNA fragments are designated herein by the standard single letter designations (A, T, C, G, U) used in the art.

"Polynucleotide" of the present invention may be in the form of RNA or in the form of DNA, which DNA includes cDNA, genomic DNA, and synthetic 25 DNA. The DNA may be double-stranded or single-stranded, and if single stranded may be the coding strand or non-coding (anti-sense) strand. The coding sequence which encodes the mature polypeptide may be identical to the coding sequence shown in SEQ ID NO:1 or in SEQ ID NO:9 or may be a different coding sequence which coding sequence, as a result of the redundancy or 30 degeneracy of the genetic code, encodes the same, mature polypeptide sequence shown in SEQ ID NO:1 or in SEQ ID NO:9.

The term "Polynucleotide encoding a polypeptide" encompasses a polynucleotide which includes only coding sequence for the polypeptide as well as a polynucleotide which includes additional coding and/or non-coding sequence.

5 "Oligonucleotides" refers to either a single stranded polynucleotide or two complementary polynucleotide strands which may be chemically synthesized. Such synthetic oligonucleotides have no 5' phosphate and thus will not ligate to another oligonucleotide without adding a phosphate with an ATP in the presence of a kinase. A synthetic oligonucleotide will ligate to a fragment that has not 10 been dephosphorylated.

15 "Amino acid residue" refers to an amino acid which is part of a polypeptide. The amino acid residues described herein are preferably in the L" isomeric form. However, residues in the D" isomeric form can be substituted for any L-amino acid residue, as long as the desired functional property is retained by the 20 polypeptide. NH<sub>2</sub> refers to the free amino group present at the amino terminus of a polypeptide. COOH refers to the free carboxy group present at the carboxyl terminus of a polypeptide. In keeping with standard polypeptide nomenclature described in *J. Biol. Chem.*, 243:3552-59 (1969) and adopted at 37 C.F.R. §§ 1.821 - 1.822, abbreviations for amino acid residues are shown in the following

Table:

**Table 1**  
Table of Correspondence

SYMBOL		
1-Letter	3-Letter	AMINO ACID
Y	Tyr	tyrosine
G	Gly	glycine
F	Phe	phenylalanine
M	Met	methionine
A	Ala	alanine
S	Ser	serine
I	Ile	isoleucine

SYMBOL			
	1-Letter	3-Letter	AMINO ACID
5	L	Leu	leucine
	T	Thr	threonine
	V	Val	valine
	P	Pro	proline
	K	Lys	lysine
10	H	His	histidine
	Q	Gln	glutamine
	E	Glu	glutamic acid
	Z	Glx	Glu and/or Gln
15	W	Trp	tryptophan
	R	Arg	arginine
	D	Asp	aspartic acid
	N	Asn	asparagine
	B	Asx	Asn and/or Asp
20	C	Cys	cysteine
	X	Xaa	Unknown or other

All amino acid residue sequences represented herein by formulae have a left to right orientation in the conventional direction of amino-terminus to carboxyl-terminus. In addition, the phrase "amino acid residue" is broadly defined to include the amino acids listed in Table 1 as well as modified and unusual amino acids, such as those referred to in 37 C.F.R. §§ 1.821-1.822, and incorporated herein by reference. A dash at the beginning or end of an amino acid residue sequence indicates a peptide bond to a further sequence of one or more amino acid residues or to an amino-terminal group such as NH<sub>2</sub> or to a carboxyl-terminal group such as COOH.

In a peptide or protein, suitable conservative substitutions of amino acids are known to those of skill in this art and may be made generally without altering

the biological activity of the resulting molecule. Those of skill in this art recognize that, in general, single amino acid substitutions in non-essential regions of a polypeptide do not substantially alter biological activity (see, e.g., Watson et al. *Molecular Biology of the Gene*, 4th Edition, 1987, The Bejacmin/Cummings Pub. co., p.224).

Such substitutions are preferably made in accordance with those set forth in TABLE 2 as follows:

TABLE 2

	Original residue	Conservative substitution
10	Ala (A)	Gly; Ser
	Arg (R)	Lys
	Asn (N)	Gln; His
15	Cys (C)	Ser
	Gln (Q)	Asn
	Glu (E)	Asp
	Gly (G)	Ala; Pro
	His (H)	Asn; Gln
20	Ile (I)	Leu; Val
	Leu (L)	Ile; Val
	Lys (K)	Arg; Gln; Glu
	Met (M)	Leu; Tyr; Ile
	Phe (F)	Met; Leu; Tyr
25	Ser (S)	Thr
	Thr (T)	Ser
	Trp (W)	Tyr
	Tyr (Y)	Trp; Phe
	Val (V)	Ile; Leu

30 Other substitutions are also permissible and may be determined empirically or in accord with known conservative substitutions.

35 "Complementing plasmid" describes plasmid vectors that deliver nucleic acids into a packaging cell line for stable integration into a chromosome in the cellular genome.

"Delivery plasmid" is a plasmid vector that carries or delivers nucleic acids encoding a therapeutic gene or gene that encodes a therapeutic product or a precursor thereof or a regulatory gene or other factor that results in a therapeutic

effect when delivered *in vivo* in or into a cell line, such as, but not limited to a packaging cell line, to propagate therapeutic viral vectors.

A variety of vectors is described herein. For example, one vector is used to deliver particular nucleic acid molecules into a packaging cell line for stable 5 integration into a chromosome. These types of vectors are generally identified herein as complementing plasmids. A further type of vector described herein carries or delivers nucleic acid molecules in or into a cell line (e.g., a packaging cell line) for the purpose of propagating therapeutic viral vectors; hence, these vectors are generally referred to herein as delivery plasmids. A third "type" of 10 vector described herein is used to carry nucleic acid molecules encoding therapeutic proteins or polypeptides or regulatory proteins or are regulatory sequences to specific cells or cell types in a subject in need of treatment; these vectors are generally identified herein as therapeutic viral vectors or recombinant adenoviral vectors or viral Ad-derived vectors and are in the form of a virus 15 particle encapsulating a viral nucleic acid containing an expression cassette for expressing the therapeutic gene.

"DNA or nucleic acid homolog" refers to a nucleic acid that includes a preselected conserved nucleotide sequence, such as a sequence encoding a therapeutic polypeptide. By the term "substantially homologous" is meant having 20 at least 80%, preferably at least 90%, most preferably at least 95% homology therewith or a less percentage of homology or identity and conserved biological activity or function.

The terms "homology" and "identity" are often used interchangeably. In this regard; degree of homology or identity may be determined, for example, by 25 comparing sequence information using a GAP computer program. The GAP program utilizes the alignment method of Needleman and Wunsch (*J. Mol. Biol.* 48:443 (1970), as revised by Smith and Waterman (*Adv. Appl. Math.* 2:482 (1981). Briefly, the GAP program defines similarity as the number of aligned symbols (i.e., nucleotides or amino acids) which are similar, divided by the total 30 number of symbols in the shorter of the two sequences. The preferred default parameters for the GAP program may include: (1) a unary comparison matrix (containing a value of 1 for identities and 0 for non-identities) and the weighted

comparison matrix of Gribskov and Burgess, *Nucl. Acids Res.* 14:6745 (1986), as described by Schwartz and Dayhoff, eds., *ATLAS OF PROTEIN SEQUENCE AND STRUCTURE*, National Biomedical Research Foundation, pp. 353-358 (1979); (2) a penalty of 3.0 for each gap and an additional 0.10 penalty for each symbol in each gap; and (3) no penalty for end gaps. Whether any two nucleic acid molecules have nucleotide sequences that are at least 80%, 85%, 90%, 95%, 96%, 97%, 98% or 99% "identical" can be determined using known computer algorithms such as the "FAST A" program, using for example, the default parameters as in Pearson and Lipman, *Proc. Natl. Acad. Sci. USA* 85:2444 (1988).

10 Alternatively the BLAST function of the National Center for Biotechnology Information database may be used to determine identity. In general, sequences are aligned so that the highest order match is obtained. "Identity" *per se* has an art-recognized meaning and can be calculated using published techniques. (See, e.g.: *Computational Molecular Biology*, Lesk, A.M., ed., Oxford University Press, New York, 1988; *Biocomputing: Informatics and Genome Projects*, Smith, D.W., ed., Academic Press, New York, 1993; *Computer Analysis of Sequence Data, Part I*, Griffin, A.M., and Griffin, H.G., eds., Humana Press, New Jersey, 1994; *Sequence Analysis in Molecular Biology*, von Heinje, G., Academic Press, 1987; and *Sequence Analysis Primer*, Gribskov, M. and Devereux, J., eds., M Stockton Press, New York, 1991). While there exist a number of methods to measure identity between two polynucleotide or polypeptide sequences, the term "identity" is well known to skilled artisans (Carillo, H. & Lipton, D., *SIAM J Applied Math* 48:1073 (1988)). Methods commonly employed to determine identity or similarity between two sequences include, but are not limited to, those disclosed in Guide to Huge Computers, Martin J. Bishop, ed., Academic Press, San Diego, 1994, and Carillo, H. & Lipton, D., *SIAM J Applied Math* 48:1073 (1988). Methods to determine identity and similarity are codified in computer programs. Preferred computer program methods to determine identity and similarity between two sequences include, but are not limited to, GCG program package (Devereux, J., *et al.*, *Nucleic Acids Research* 12(I):387 (1984)), BLASTP, BLASTN, FASTA (Atschul, S.F., *et al.*, *J Molec Biol* 215:403 (1990)).

The term "identity" represents a comparison between a test and a reference polypeptide or polynucleotide. For example, a test polypeptide may be defined as any polypeptide that is 90% or more identical to a reference polypeptide. As used herein, the term at least "90% identical to" refers to percent identities from 5 90 to 99.99 relative to the reference polypeptides. Identity at a level of 90% or more is indicative of the fact that, assuming for exemplification purposes a test and reference polynucleotide length of 100 amino acids are compared. No more than 10% (i.e., 10 out of 100) amino acids in the test polypeptide differs from that of the reference polypeptides. Similar comparisons may be made between a test 10 and reference polynucleotides. Such differences may be represented as point mutations randomly distributed over the entire length of an amino acid sequence or they may be clustered in one or more locations of varying length up to the maximum allowable, e.g. 10/100 amino acid difference (approximately 90% identity). Differences are defined as nucleic acid or amino acid substitutions, or 15 deletions.

The terms "gene therapy" and "genetic therapy" refer to the transfer of heterologous DNA to the certain cells, target cells, of a mammal, particularly a human, with a disorder or conditions for which such therapy is sought. The DNA is introduced into the selected target cells in a manner such that the heterologous 20 DNA is expressed and a therapeutic product encoded thereby is produced. Alternatively, the heterologous DNA may in some manner mediate expression of DNA that encodes the therapeutic product, it may encode a product, such as a peptide or RNA that in some manner mediates, directly or indirectly, expression 25 of a therapeutic product. Genetic therapy may also be used to nucleic acid encoding a gene product replace a defective gene or supplement a gene product produced by the mammal or the cell in which it is introduced. The introduced nucleic acid may encode a therapeutic compound, such as a growth factor inhibitor thereof, or a tumor necrosis factor or inhibitor thereof, such as a receptor 30 therefor, that is not normally produced in the mammalian host or that is not produced in therapeutically effective amounts or at a therapeutically useful time. The heterologous DNA encoding the therapeutic product may be modified prior

to introduction into the cells of the afflicted host in order to enhance or otherwise alter the product or expression thereof.

"Heterologous DNA" is DNA that encodes RNA and proteins that are not normally produced *in vivo* by the cell in which it is expressed or that mediates or encodes mediators that alter expression of endogenous DNA by affecting transcription, translation, or other regulatable biochemical processes.

Heterologous DNA may also be referred to as foreign DNA. Any DNA that one of skill in the art would recognize or consider as heterologous or foreign to the cell in which it is expressed is herein encompassed by heterologous DNA.

Examples of heterologous DNA include, but are not limited to, DNA that encodes traceable marker proteins, such as a protein that confers drug resistance, DNA that encodes therapeutically effective substances, such as anti-cancer agents, enzymes and hormones, and DNA that encodes other types of proteins, such as antibodies. Antibodies that are encoded by heterologous DNA may be secreted or expressed on the surface of the cell in which the heterologous DNA has been introduced. Hence, "heterologous DNA" or "foreign DNA", refers to a DNA molecule not present in the exact orientation and position as the counterpart DNA molecule found in the corresponding wild-type adenovirus. It may also refer to a DNA molecule from another organism or species (*i.e.*, exogenous) or from another Ad serotype.

"Therapeutically effective DNA product" is a product that is encoded by heterologous DNA so that, upon introduction of the DNA into a host, a product is expressed that effectively ameliorates or eliminates the symptoms, manifestations of an inherited or acquired disease or that cures said disease. Typically, DNA encoding the desired heterologous DNA is cloned into a plasmid vector and introduced by routine methods, such as calcium-phosphate mediated DNA uptake (see, (1981) Somat. Cell. Mol. Genet. 7:603-616) or micro injection, into producer cells, such as packaging cells. After amplification in producer cells, the vectors that contain the heterologous DNA are introduced into selected target cells.

"Expression or delivery vector" refers to any plasmid or virus into which a foreign or heterologous DNA may be inserted for expression in a suitable host

cell -- *i.e.*, the protein or polypeptide encoded by the DNA is synthesized in the host cell's system. Vectors capable of directing the expression of DNA segments (genes) encoding one or more proteins are referred to herein as "expression vectors." Also included are vectors that allow cloning of cDNA (complementary DNA) from mRNAs produced using reverse transcriptase.

"Gene" is a nucleic acid molecule whose nucleotide sequence encodes RNA or polypeptide. A gene can be either RNA or DNA. Genes may include regions preceding and following the coding region (leader and trailer) as well as intervening sequences (introns) between individual coding segments (exons).

"Isolated" with reference to a nucleic acid molecule, polypeptide, or other biomolecule, means that the nucleic acid or polypeptide has separated from the genetic environment from which the polypeptide or nucleic acid were obtained. It may also mean altered from the natural state. For example, a polynucleotide or a polypeptide naturally present in a living animal is not "isolated," but the same polynucleotide or polypeptide separated from the coexisting materials of its natural state is "isolated", as the term is employed herein. Thus, a polypeptide or polynucleotide produced and/or contained within a recombinant host cell is considered isolated. Also intended as an "isolated polypeptide" or an "isolated polynucleotide" are polypeptides or polynucleotides that have been purified, partially or substantially, from a recombinant host cell or from a native source. For example, a recombinantly produced version of a compounds can be substantially purified by the one-step method described in Smith and Johnson, *Gene* 67:31-40 (1988). The terms "isolated" and "purified" are sometimes used interchangeably. Such polynucleotide could be part of a vector and/or such polynucleotide or polypeptide could be part of a composition, and still be isolated in that such vector or composition is not part of its natural environment.

By "isolated polynucleotide" is meant that the nucleic acid is free of the coding sequences of those genes that, in the naturally-occurring genome of the organism (if any) immediately flank the gene encoding the nucleic acid of interest. Isolated DNA may be single-stranded or double-stranded, and may be genomic DNA, cDNA, recombinant hybrid DNA, or synthetic DNA. It may be

identical to a native DNA sequence, or may differ from such sequence by the deletion, addition, or substitution of one or more nucleotides.

"Isolated" or "purified" as it refers to preparations made from biological cells or hosts means any cell extract containing the indicated DNA or protein including a crude extract of the DNA or protein of interest. For example, in the case of a protein, a purified preparation can be obtained following an individual technique or a series of preparative or biochemical techniques and the DNA or protein of interest can be present at various degrees of purity in these preparations. The procedures may include for example, but are not limited to, ammonium sulfate fractionation, gel filtration, ion exchange change chromatography, affinity chromatography, density gradient centrifugation and electrophoresis.

A preparation of DNA or protein that is "substantially pure" or "isolated" means a preparation free from naturally occurring materials with which such DNA or protein is normally associated in nature. "Essentially pure" should be understood to mean a "highly" purified preparation that contains at least 95% of the DNA or protein of interest.

"Packaging cell line" is a cell line that provides a missing gene product or its equivalent.

"Adenovirus viral particle" is the minimal structural or functional unit of a virus. A virus can refer to a single particle, a stock of particles or a viral genome. The adenovirus (Ad) particle is relatively complex and may be resolved into various substructures.

"Post-transcription regulatory element (PRE)" is a regulatory element found in viral or cellular messenger RNA that is not spliced, i.e. intronless messages. Examples include, but are not limited to, human hepatitis virus, woodchuck hepatitis virus, the TK gene and mouse histone gene. The PRE may be placed before a polyA sequence and after a heterologous DNA sequence.

"Pseudo typing" describes the production of adenoviral vectors having modified capsid protein or capsid proteins from a different serotype than the serotype of the vector itself. One example, is the production of an adenovirus 5 vector particle containing an Ad37 fiber protein. This may be accomplished by

producing the adenoviral vector in packaging cell lines expressing different fiber proteins.

"Promoters of interest herein" may be inducible or constitutive. Inducible promoters will initiate transcription only in the presence of an additional molecule; constitutive promoters do not require the presence of any additional molecule to regulate gene expression. A regulatable or inducible promoter may also be described as a promoter where the rate or extent of RNA polymerase binding and initiation is modulated by external stimuli. Such stimuli include, but are not limited to various compounds or compositions, light, heat, stress and chemical energy sources. Inducible, suppressible and repressible promoters are considered regulatable promoters. Preferred promoters herein, are promoters that are selectively expressed in ocular cells, particularly photo receptor cells.

"Receptor" refers to a biologically active molecule that specifically binds to (or with) other molecules. The term "receptor protein" may be used to more specifically indicate the proteinaceous nature of a specific receptor.

"Recombinant" refers to any progeny formed as the result of genetic engineering. This may also be used to describe a virus formed by recombination of plasmids in a packaging cell.

"Transgene" or "therapeutic nucleic acid molecule" includes DNA and RNA molecules encoding an RNA or polypeptide. Such molecules may be "native" or naturally-derived sequences; they may also be "non-native" or "foreign" that are naturally- or recombinantly-derived. The term "transgene," which may be used interchangeably herein with the term "therapeutic nucleic acid molecule," is often used to describe a heterologous or foreign (exogenous) gene that is carried by a viral vector and transduced into a host cell. Therapeutic nucleotide nucleic acid molecules include antisense sequences or nucleotide sequences which may be transcribed into antisense sequences. Therapeutic nucleotide sequences (or transgenes) all include nucleic acid molecules that function to produce a desired effect in the cell or cell nucleus into which said therapeutic sequences are delivered. For example, a therapeutic nucleic acid molecule can include a sequence of nucleotides that encodes a functional protein

intended for delivery into a cell which is unable to produce that functional protein.

"Vitreous of the eye" refers to a material that fills the chamber behind the lens of the eye (i.e., vitreous humor or vitreous body).

5 "Promoter region" refers to the portion of DNA of a gene that controls transcription of the DNA to which it is operatively linked. The promoter region includes specific sequences of DNA that are sufficient for RNA polymerase recognition, binding and transcription initiation. This portion of the promoter region is referred to as the promoter. In addition, the promoter region includes  
10 sequences that modulate this recognition, binding and transcription initiation activity of the RNA polymerase. These sequences may be *cis* acting or may be responsive to *trans* acting factors. Promoters, depending upon the nature of the regulation, may be constitutive or regulated.

15 "Operatively linked" means that the sequences or segments have been covalently joined into one piece of DNA, whether in single or double stranded form, whereby control sequences on one segment control expression or replication or other such control of other segments. The two segments are not necessarily contiguous, however.

20 "Package" refers to a solid matrix or material such as glass, plastic (e.g., polyethylene, polypropylene or polycarbonate), paper, foil and the like capable of holding within fixed limits a polypeptide, polyclonal antibody, or monoclonal antibody of the present invention. Thus, for example, a package can be a glass vial used to contain milligram quantities of a contemplated polypeptide or it can be a micro titer plate well to which microgram quantities of a contemplated  
25 polypeptide or antibody have been operatively affixed (i.e., linked) so as to be capable of being immunologically bound by an antibody or antigen, respectively.

30 "Instructions for use" typically include a tangible expression describing the reagent concentration or at least one assay method parameter, such as the relative amounts of reagent and sample to be admixed, maintenance time periods for reagent/sample admixtures, temperature, buffer conditions and the like.

"Diagnostic system" in the context of the present invention also includes a label or indicating means capable of signaling the formation of an

immunocomplex containing a polypeptide or antibody molecule of the present invention.

"Complex" as used herein refers to the product of a specific binding reaction such as an antibody-antigen or receptor-ligand reaction. Exemplary complexes are immunoreaction products.

"Label" and "Indicating means" in their various grammatical forms refer to single atoms and molecules that are either directly or indirectly involved in the production of a detectable signal to indicate the presence of a complex. Any label or indicating means can be linked to or incorporated in an expressed protein, polypeptide, or antibody molecule that is part of an antibody or monoclonal antibody composition of the present invention or used separately, and those atoms or molecules can be used alone or in conjunction with additional reagents. Such labels are themselves well-known in clinical diagnostic chemistry and constitute a part of this invention only insofar as they are utilized with otherwise novel proteins methods and/or systems.

The terms "fragment," "derivative" and "analog", when referring to a polypeptide, means a polypeptide which retains substantially the same biological function or activity as such polypeptide. Thus, an analog includes a proprotein which can be activated by cleavage of the proprotein portion to produce an active mature polypeptide.

A "specific binding agent" is a molecular entity capable of selectively binding a reagent species of the present invention or a complex containing such a species, but is not itself a polypeptide or antibody molecule composition of the present invention. Exemplary specific binding agents are second antibody molecules, complement proteins or fragments thereof, S. aureus protein A, and the like.

"ELISA" refers to an enzyme-linked immunosorbent assay that employs an antibody or antigen bound to a solid phase and an enzyme-antigen or enzyme-antibody conjugate to detect and quantify the amount of an antigen present in a sample. A description of the ELISA technique is found in Sites et al., *Basic and Clinical Immunology*, 4<sup>th</sup> Ed., Chap. 22, Lange Medical Publications, Los Altos,

CA (1982) and in U.S. Patent No. 3,654,090; Patent No. 3,850,752; and Patent No. 4,016,043, which are all incorporated herein by reference.

The present invention further relates to variants of the hereinabove described polynucleotides which encode for fragments, analogs and derivatives of the polypeptide having the amino acid sequence of SEQ ID NO:9 or the polypeptide encoded by the cDNA of SEQ ID NO:9. The variant of the polynucleotide may be a naturally occurring allelic variant of the polynucleotide or a non-naturally occurring variant of the polynucleotide. Thus, the present invention includes polynucleotides encoding the same mature polypeptide as shown SEQ ID NO:9 or the same mature polypeptide encoded by the cDNA of SEQ ID NO:9 as well as variants of such polynucleotides which variants encode for an fragment, derivative or analog of the polypeptide of SEQ ID NO:9 or the polypeptide encoded by SEQ ID NO:9. Such nucleotide variants include deletion variants, substitution variants and addition or insertion variants.

As hereinabove indicated, the polynucleotide may have a coding sequence which is a naturally occurring allelic variant of the coding sequence shown in SEQ ID NO:1 or SEQ ID NO:9. As known in the art, an "allelic variant" is an alternate form of a polynucleotide sequence which have a substitution, deletion or addition of one or more nucleotides, which does not substantially alter the function of the encoded polypeptide.

The present invention also includes polynucleotides, wherein the coding sequence for the mature polypeptide may be fused in the same reading frame to a polynucleotide which aids in expression and secretion of a polypeptide from a host cell, for example, a leader sequence which functions as a secretory sequence for controlling transport of a polypeptide from the cell. The polypeptide having a leader sequence is a preprotein and may have the leader sequence cleaved by the host cell to form the mature form of the polypeptide. The polynucleotides may also encode for a proprotein which is the mature protein plus additional 5' amino acid residues. A mature protein having a prosequence is a proprotein and is an inactive form of the protein. Once the prosequence is cleaved an active mature protein remains.

Thus, for example, the polynucleotide of the present invention may encode for a mature protein, or for a protein having a prosequence or for a protein having both a prosequence and presequence (leader sequence).

The polynucleotides of the present invention may also have the coding sequence fused in frame to a marker sequence which allows for purification of the polypeptide of the present invention. The marker sequence may be a hexa-histidine tag supplied by a pQE-9 vector to provide for purification of the mature polypeptide fused to the marker in the case of a bacterial host, or, for example, the marker sequence may be a hemagglutinin (HA) tag when a mammalian host, e.g. COS-7 cells, is used. The HA tag corresponds to an epitope derived from the influenza hemagglutinin protein (Wilson, I., et al., *Cell*, 37:767 (1984)).

The present invention further relates to polynucleotides which hybridize to the hereinabove-described sequences if there is at least 50% and preferably 70% identity between the sequences. The present invention particularly relates to polynucleotides which hybridize under stringent conditions to the hereinabove-described polynucleotides. As herein used, the term "stringent conditions" means hybridization will occur only if there is at least 95% and preferably at least 97% identity between the sequences. The polynucleotides which hybridize to the hereinabove described polynucleotides in a preferred embodiment encode polypeptides which retain substantially the same biological function or activity as the mature polypeptide encoded by the cDNA of SEQ ID NO:9.

The polypeptide of the present invention may be a recombinant polypeptide, a natural polypeptide or a synthetic polypeptide, preferably a recombinant polypeptide.

The fragment, derivative or analog of the polypeptide of SEQ ID NO:9 or that encoded by the polynucleotide of SEQ ID NO:9 may be (i) one in which one or more of the amino acid residues are substituted with a conserved or non-conserved amino acid residue (preferably a conserved amino acid residue) and such substituted amino acid residue may or may not be one encoded by the genetic code, or (ii) one in which one or more of the amino acid residues includes a substituent group, or (iii) one in which the mature polypeptide is fused with another compound, such as a compound to increase the half-life of the

polypeptide (for example, polyethylene glycol), or (iv) one in which the additional amino acids are fused to the mature polypeptide, such as a leader or secretory sequence or a sequence which is employed for purification of the mature polypeptide or a proprotein sequence. Such fragments, derivatives and 5 analogs are deemed to be within the scope of those skilled in the art from the teachings herein.

The polypeptides and polynucleotides of the present invention are preferably provided in an isolated form, and preferably are purified to homogeneity.

10 The present invention also relates to vectors which include polynucleotides of the present invention, host cells which are genetically engineered with vectors of the invention and the production of polypeptides of the invention by recombinant techniques.

15 Host cells are genetically engineered (transduced or transformed or transfected) with the vectors of this invention which may be, for example, a cloning vector or an expression vector. The vector may be, for example, in the form of a plasmid, a viral particle, a phage, etc. The engineered host cells can be cultured in conventional nutrient media modified as appropriate for activating 20 promoters, selecting transformants or amplifying the tRNA synthetase polypeptide genes. The culture conditions, such as temperature, pH and the like, are those previously used with the host cell selected for expression, and will be apparent to the ordinarily skilled artisan.

25 The polynucleotide of the present invention may be employed for producing a polypeptide by recombinant techniques. Thus, for example, the polynucleotide sequence may be included in any one of a variety of expression vehicles, in particular vectors or plasmids for expressing a polypeptide. Such vectors include chromosomal, nonchromosomal and synthetic DNA sequences, e.g., derivatives of SV40; bacterial plasmids; phage DNA; yeast plasmids; vectors derived from combinations of plasmids and phage DNA, viral DNA such as vaccinia, 30 adenovirus, fowl pox virus, and pseudo rabies. A preferred vector is pET20b. However, any other plasmid or vector may be used as long as it is replicable and viable in the host.

As hereinabove described, the appropriate DNA sequence may be inserted into the vector by a variety of procedures. In general, the DNA sequence is inserted into an appropriate restriction endonuclease sites by procedures known in the art. Such procedures and others are deemed to be within the scope of those skilled in the art.

The DNA sequence in the expression vector is operatively linked to an appropriate expression control sequence(s) (promoter) to direct mRNA synthesis. As representative examples of such promoters, there may be mentioned: LTR or SV40 promoter, the *E. coli*. lac or trp, the phage lambda  $P_L$  promoter and other promoters known to control expression of genes in prokaryotic or eukaryotic cells or their viruses. The expression vector also contains a ribosome binding site for translation initiation and a transcription terminator. The vector may also include appropriate sequences for amplifying expression.

In addition, the expression vectors preferably contain a gene to provide a phenotypic trait for selection of transformed host cells such as dihydrofolate reductase or neomycin resistance for eukaryotic cell culture, or such as tetracycline or ampicillin resistance in *E. coli*.

The vector containing the appropriate DNA sequence as herein above described, as well as an appropriate promoter or control sequence, may be employed to transform an appropriate host to permit the host to express the protein. As representative examples of appropriate hosts, there may be mentioned: bacterial cells, such as *E. coli*, *Salmonella typhimurium*, *Streptomyces*; fungal cells, such as yeast; insect cells, such as *Drosophila* and Sf9; animal cells such as CHO, COS or Bowes melanoma; plant cells, etc. The selection of an appropriate host is deemed to be within the scope of those skilled in the art from the teachings herein.

More particularly, the present invention also includes recombinant constructs comprising one or more of the sequences as broadly described above. The constructs comprise a vector, such as a plasmid or viral vector, into which a sequence of the invention has been inserted, in a forward or reverse orientation. In a preferred aspect of this embodiment, the construct further comprises regulatory sequences, including, for example, a promoter, operably linked to the sequence.

Large numbers of suitable vectors and promoters are known to those of skill in the art, and are commercially available. The following vectors are provided by way of example. Bacterial: pQE70, pQE-9 (Qiagen), pBs, phage script, PsiX174, pBluescript SK, pBsKS, pNH8a, pNH16a, pNH18a, pNH46a (Stratagene);  
5 pTrc99A, pKK223-3, pKK233-3, pDR540, PRIT5 (Pharmacia). Eukaryotic: pWLneo, pSV2cat, pOG44, pXT1, pSG (Stratagene) pSVK3, pBPV, PMSG, pSVL (Pharmacia) and pET20B. In one preferred embodiment, the vector is pET20B. However, any other plasmid or vector may be used as long as they are replicable and viable in the host.

10 Promoter regions can be selected from any desired gene using CAT (chloramphenicol transferase) vectors or other vectors with selectable markers. Two appropriate vectors are pKK232-8 and pCM7. Particular named bacterial promoters include lacI, lacZ, T3, T7, gpt, lambda P<sub>R</sub>, PL and trp. Eukaryotic promoters include CMV immediate early, HSV thymidine kinase, early and late  
15 SV40, LTRs from retrovirus, and mouse metallothionein-I. Selection of the appropriate vector and promoter is well within the level of ordinary skill in the art.

20 In a further embodiment, the present invention relates to host cells containing the above-described construct. The host cell can be a higher eukaryotic cell, such as a mammalian cell, or a lower eukaryotic cell, such as a yeast cell, or the host cell can be a prokaryotic cell, such as a bacterial cell. Introduction of the construct into the host cell can be effected by calcium phosphate transfection, DEAE-Dextran mediated transfection, or electroporation (Davis, L., Dibner, M., Battey, I., *Basic Methods in Molecular Biology*, 1986)).

25 The constructs in host cells can be used in a conventional manner to produce the gene product encoded by the recombinant sequence. Alternatively, the polypeptides of the invention can be synthetically produced by conventional peptide synthesizers.

30 Mature proteins can be expressed in mammalian cells, yeast, bacteria, or other cells under the control of appropriate promoters. Cell-free translation systems can also be employed to produce such proteins using RNAs derived from the DNA constructs of the present invention. Appropriate cloning and expression

vectors for use with prokaryotic and eukaryotic hosts are described by Sambrook et al., Molecular Cloning: A Laboratory Manual, Second Edition, (Cold Spring Harbor, N.Y., 1989), the disclosure of which is hereby incorporated by reference.

Transcription of a DNA encoding the polypeptides of the present invention by higher eukaryotes is increased by inserting an enhancer sequence into the vector. Enhancers are *cis*-acting elements of DNA, usually about from 10 to 300 bp, that act on a promoter to increase its transcription. Examples include the SV40 enhancer on the late side of the replication origin (bp 100 to 270), a cytomegalovirus early promoter enhancer, a polyoma enhancer on the late side of the replication origin, and adenovirus enhancers.

Generally, recombinant expression vectors will include origins of replication and selectable markers permitting transformation of the host cell, e.g., the ampicillin resistance gene of *E. coli* and *S. cerevisiae* TRP1 gene, and a promoter derived from a highly-expressed gene to direct transcription of a downstream structural sequence. Such promoters can be derived from operons encoding glycolytic enzymes such as 3-phosphoglycerate kinase (PGK),  $\alpha$ -factor, acid phosphatase, or heat shock proteins, among others. The heterologous structural sequence is assembled in appropriate phase with translation initiation and termination sequences, and preferably, a leader sequence capable of directing secretion of translated protein into the periplasmic space or extracellular medium. Optionally, the heterologous sequence can encode a fusion protein including an N-terminal identification peptide imparting desired characteristics, e.g., stabilization or simplified purification of expressed recombinant product.

Following transformation of a suitable host strain and growth of the host strain to an appropriate cell density, the selected promoter is derepressed by appropriate means (e.g., temperature shift or chemical induction) and cells are cultured for an additional period.

Cells are typically harvested by centrifugation, disrupted by physical or chemical means, and the resulting crude extract retained for further purification.

Microbial cells employed in expression of proteins can be disrupted by any convenient method, including freeze-thaw cycling, sonication, mechanical disruption, or use of cell lysing agents.

Various mammalian cell culture systems can also be employed to express recombinant protein. Examples of mammalian expression systems include the COS-7 lines of monkey kidney fibroblasts, described by Gluzman, Cell, 23:175 (1981), and other cell lines capable of expressing a compatible vector, for example, the C127, 3T3, CHO, HeLa and BHK cell lines. Mammalian expression vectors will comprise an origin of replication, a suitable promoter and enhancer, and also any necessary ribosome binding sites, polyadenylation site, splice donor and acceptor sites, transcriptional termination sequences, and 5' flanking nontranscribed sequences. DNA sequences derived from the SV40 viral genome, for example, SV40 origin, early promoter, enhancer, splice, and polyadenylation sites may be used to provide the required nontranscribed genetic elements.

Polypeptides are recovered and purified from recombinant cell cultures by methods used heretofore, including ammonium sulfate or ethanol precipitation, acid extraction, anion or cation exchange chromatography, phosphocellulose chromatography, hydrophobic interaction chromatography, affinity chromatography, hydroxyapatite chromatography and lectin chromatography. It is preferred to have low concentrations (approximately 0.1-5 mM) of calcium ion present during purification (Price, et al., J. Biol. Chem., 244:917 (1969)). Protein refolding steps can be used, as necessary, in completing configuration of the mature protein. Finally, high performance liquid chromatography (HPLC) can be employed for final purification steps.

The polypeptides of the present invention may be a naturally purified product, or a product of chemical synthetic procedures, or produced by recombinant techniques from a prokaryotic or eukaryotic host (for example, by bacterial, yeast, higher plant, insect and mammalian cells in culture). Depending upon the host employed in a recombinant production procedure, the polypeptides of the present invention may be glycosylated with mammalian or other eukaryotic carbohydrates or may be non-glycosylated.

The polypeptides of the present invention may be modified to improve stability and increase potency by means known in the art. For example, L-amino acids can be replaced by D-amino acids, the amino terminus can be acetylated, or

the carboxyl terminus modified, e.g., ethyl amine-capped (Dawson, D.W., et al., Mol. Pharmacol., 55: 332-338 (1999)).

Angiogenic tRNA synthetase polypeptides are useful as wound healing agents, particularly where it is necessary to re-vascularize damaged tissues, or 5 where new capillary angiogenesis is important. Therefore, it may be used for treatment of full-thickness wounds such as dermal ulcers, including pressure sores, venous ulcers, and diabetic ulcers. In addition, it can be used in the treatment of full-thickness burns and injuries where angiogenesis is desired to 10 prepare the burn in injured sites for a skin graft and flap. In this case, it should be applied directly at the sites. Similarly angiogenic tRNA synthetase polypeptides 15 polypeptides can be used in plastic surgery when reconstruction is required following a burn, other trauma, or even for cosmetic purposes.

Since angiogenesis is important in keeping wounds clean and non-infected, angiogenic tRNA synthetase polypeptides may be used in association with 20 surgery and following the repair of cuts. It should be particularly useful in the treatment of abdominal wounds where there is a high risk of infection.

Angiogenic tRNA synthetase polypeptides can be used for the promotion of 25 endothelialization in vascular graft surgery. In the case of vascular grafts using either transplanted or synthetic material, angiogenic tyrRS peptides can be applied to the surface of the graft, preferably in a pharmaceutically appropriate excipient. In one embodiment, the pharmaceutically appropriate excipient further provides 30 for the continuous release of angiogenic tyrRS peptides.

Angiogenic tRNA synthetase therapy can be used to repair the damage of myocardial infarction. In one preferred embodiment, angiogenic tyrRS therapy 25 can be used in conjunction with coronary bypass surgery by stimulating the growth of the transplanted tissue. In one preferred embodiment, angiogenic tRNA synthetase therapy can be administered by direct myocardial injection of angiogenic tRNA synthetase polypeptides or polynucleotides encoding 30 angiogenic tRNA synthetase polypeptides. See Losodo, D.W., et al., Circulation, 98: 2800-2804 (1998).

In another embodiment, angiogenic tRNA synthetase therapy can be used in conjunction with angiography to administer the angiogenic tRNA synthetase

polypeptides or polynucleotides encoding angiogenic tRNA synthetase polypeptides directly to the lumen and wall of the blood vessel.

Similarly, tRNA synthetase therapy can be used to administer the angiogenic or angiostatic tRNA synthetase polypeptides or polynucleotides 5 encoding angiogenic or angiostatic tRNA synthetase polypeptides directly to the lumen and wall of other hollow organs, such as the uterus.

The polypeptide of the present invention may also be employed in accordance with the present invention by expression of such polypeptide *in vivo*, which is often referred to as "gene therapy."

10 Thus, for example, cells such as bone marrow cells may be engineered with a polynucleotide (DNA or RNA) encoding for the polypeptide *ex vivo*, the engineered cells are then provided to a patient to be treated with the polypeptide. Such methods are well-known in the art. For example, cells may be engineered by procedures known in the art by use of a retroviral particle containing RNA 15 encoding for the polypeptide of the present invention. Similarly, cells may be engineered *in vivo* for expression of the polypeptide *in vivo*, for example, by procedures known in the art. As known in the art, a producer cell for producing a retroviral particle containing RNA encoding the polypeptide of the present invention may be administered to a patient for engineering cells *in vivo* and expression of the polypeptide *in vivo*. These and other methods for administering 20 a polypeptide of the present invention by such methods should be apparent to those skilled in the art from the teachings of the present invention. For example, the expression vehicle for engineering cells may be other than a retroviral particle, for example, an adenovirus, which may be used to engineering cells *in vivo* after 25 combination with a suitable delivery vehicle.

Various viral vectors that can be utilized for gene therapy as taught herein include adenovirus, herpes virus, vaccinia, adeno-associated virus (AAV), or, preferably, an RNA virus such as a retrovirus. Preferably, the retroviral vector is a derivative 30 of a murine or avian retrovirus, or is a lentiviral vector. The preferred retroviral vector is a lentiviral vector. Examples of retroviral vectors in which a single foreign gene can be inserted include, but are not limited to: Moloney murine leukemia virus (MoMuLV), Harvey murine sarcoma virus (HaMuSV), murine

5 mammary tumor virus (MuMTV), SIV, BIV, HIV and Rous Sarcoma Virus (RSV). A number of additional retroviral vectors can incorporate multiple genes. All of these vectors can transfer or incorporate a gene for a selectable marker so that transduced cells can be identified and generated. By inserting a zinc finger  
10 derived-DNA binding polypeptide sequence of interest into the viral vector, along with another gene that encodes the ligand for a receptor on a specific target cell, for example, the vector is made target specific. Retroviral vectors can be made target specific by inserting, for example, a polynucleotide encoding a protein. Preferred targeting is accomplished by using an antibody to target the retroviral  
15 vector. Those of skill in the art will know of, or can readily ascertain without undue experimentation, specific polynucleotide sequences which can be inserted into the retroviral genome to allow target specific delivery of the retroviral vector containing the zinc finger-nucleotide binding protein polynucleotide.

15 Since recombinant retroviruses are defective, they require assistance in order to produce infectious vector particles. This assistance can be provided, for example, by using helper cell lines that contain plasmids encoding all of the structural genes of the retrovirus under the control of regulatory sequences within the LTR. These plasmids are missing a nucleotide sequence which enables the packaging mechanism to recognize an RNA transcript for encapsitation. Helper  
20 cell lines which have deletions of the packaging signal include but are not limited to  $\Psi$ 2, PA317 and PA12, for example. These cell lines produce empty virions, since no genome is packaged. If a retroviral vector is introduced into such cells in which the packaging signal is intact, but the structural genes are replaced by other genes of interest, the vector can be packaged and vector virion produced. The  
25 vector virions produced by this method can then be used to infect a tissue cell line, such as NIH 3T3 cells, to produce large quantities of chimeric retroviral virions.

30 Another targeted delivery system for polynucleotides encoding zinc finger derived-DNA binding polypeptides is a colloidal dispersion system. Colloidal dispersion systems include macromolecule complexes, nanocapsules, micro spheres, beads, and lipid-based systems including oil-in-water emulsions, micelles, mixed micelles, and liposomes. The preferred colloidal system of this

invention is a liposome. Liposomes are artificial membrane vesicles which are useful as delivery vehicles *in vitro* and *in vivo*. It has been shown that large unilamellar vesicles (LUV), which range in size from 0.2-4.0  $\mu\text{m}$  can encapsulate a substantial percentage of an aqueous buffer containing large macromolecules.

5 RNA, DNA and intact virions can be encapsulated within the aqueous interior and be delivered to cells in a biologically active form (Fraley, *et al.*, *Trends Biochem. Sci.*, 6:77, 1981). In addition to mammalian cells, liposomes have been used for delivery of polynucleotides in plant, yeast and bacterial cells. In order for a liposome to be an efficient gene transfer vehicle, the following characteristics

10 should be present: (1) encapsulation of the genes of interest at high efficiency while not compromising their biological activity; (2) preferential and substantial binding to a target cell in comparison to non-target cells; (3) delivery of the aqueous contents of the vesicle to the target cell cytoplasm at high efficiency; and (4) accurate and effective expression of genetic information (Mannino, *et al.*,

15 *Biotechniques*, 6:682, 1988).

The composition of the liposome is usually a combination of phospholipids, particularly high-phase-transition-temperature phospholipids, usually in combination with steroids, especially cholesterol. Other phospholipids or other lipids may also be used. The physical characteristics of liposomes depend on pH, ionic strength, and the presence of divalent cations.

20 Examples of lipids useful in liposome production include phosphatidyl compounds, such as phosphatidylglycerol, phosphatidylcholine, phosphatidylserine, phosphatidylethanolamine, sphingolipids, cerebrosides, and gangliosides. Particularly useful are diacylphosphatidylglycerols, where the lipid moiety contains from 14-18 carbon atoms, particularly from 16-18 carbon atoms, and is saturated. Illustrative phospholipids include egg phosphatidylcholine, dipalmitoylphosphatidylcholine and distearoylphosphatidylcholine.

25 The targeting of liposomes has been classified based on anatomical and mechanistic factors. Anatomical classification is based on the level of selectivity, for example, organ-specific, cell-specific, and organelle-specific. Mechanistic targeting can be distinguished based upon whether it is passive or active. Passive targeting utilizes the natural tendency of liposomes to distribute to cells of the

reticulo-endothelial system (RES) in organs which contain sinusoidal capillaries. 5 Active targeting, on the other hand, involves alteration of the liposome by coupling the liposome to a specific ligand such as a monoclonal antibody, sugar, glycolipid, or protein, or by changing the composition or size of the liposome in order to achieve targeting to organs and cell types other than the naturally occurring sites of localization.

10 The surface of the targeted delivery system may be modified in a variety of ways. In the case of a liposomal targeted delivery system, lipid groups can be incorporated into the lipid bilayer of the liposome in order to maintain the targeting ligand in stable association with the liposomal bilayer. Various linking groups can be used for joining the lipid chains to the targeting ligand.

15 In general, the compounds bound to the surface of the targeted delivery system will be ligands and receptors which will allow the targeted delivery system to find and "home in" on the desired cells. A ligand may be any compound of interest which will bind to another compound, such as a receptor.

20 In general, surface membrane proteins which bind to specific effector molecules are referred to as receptors. In the present invention, antibodies are preferred receptors. Antibodies can be used to target liposomes to specific cell-surface ligands. For example, certain antigens expressed specifically on tumor cells, referred to as tumor-associated antigens (TAAs), may be exploited for the purpose of targeting antibody-zinc finger-nucleotide binding protein-containing liposomes directly to the malignant tumor. Since the zinc finger-nucleotide 25 binding protein gene product may be indiscriminate with respect to cell type in its action, a targeted delivery system offers a significant improvement over randomly injecting non-specific liposomes. A number of procedures can be used to covalently attach either polyclonal or monoclonal antibodies to a liposome bilayer. Antibody-targeted liposomes can include monoclonal or polyclonal antibodies or fragments thereof such as Fab, or F(ab')<sub>2</sub>, as long as they bind 30 efficiently to an the antigenic epitope on the target cells. Liposomes may also be targeted to cells expressing receptors for hormones or other serum factors.

There are available to one skilled in the art multiple viral and non-viral methods suitable for introduction of a nucleic acid molecule into a target cell.

Genetic manipulation of primary tumor cells has been described previously (Patel et al., 1994). Genetic modification of a cell may be accomplished using one or more techniques well known in the gene therapy field (Human Gene Therapy, April 1994, Vol. 5, p. 543-563; Mulligan, R.C. 1993). Viral 5 transduction methods may comprise the use of a recombinant DNA or an RNA virus comprising a nucleic acid sequence that drives or inhibits expression of a protein having sialyltransferase activity to infect a target cell. A suitable DNA virus for use in the present invention includes but is not limited to an adenovirus (Ad), adeno-associated virus (AAV), herpes virus, vaccinia virus or a polio virus. 10 A suitable RNA virus for use in the present invention includes but is not limited to a retrovirus or Sindbis virus. It is to be understood by those skilled in the art that several such DNA and RNA viruses exist that may be suitable for use in the present invention.

Adenoviral vectors have proven especially useful for gene transfer into 15 eukaryotic cells (Stratford-Perricaudet and Perricaudet. 1991). Adenoviral vectors have been successfully utilized to study eukaryotic gene expression (Levrero, M., et al. 1991). vaccine development (Graham and Prevec, 1992), and in animal models (Stratford-Perricaudet, et al. 1992.; Rich, et al. 1993). The first trial of Ad-mediated gene therapy in human was the transfer of the cystic fibrosis 20 transmembrane conductance regulator (CFTR) gene to lung (Crystal, et al., 1994). Experimental routes for administrating recombinant Ad to different tissues *in vivo* have included intra tracheal instillation (Rosenfeld, et al. 1992) injection into muscle (Quantin, B., et al. 1992), peripheral intravenous injection (Herz and Gerard, 1993) and stereotactic inoculation to brain (Le Gal La Salle, et al. 1993). 25 The adenoviral vector, then, is widely available to one skilled in the art and is suitable for use in the present invention.

Adeno-associated virus (AAV) has recently been introduced as a gene 30 transfer system with potential applications in gene therapy. Wild-type AAV demonstrates high-level infectivity, broad host range and specificity in integrating into the host cell genome (Hermonat and Muzyczka. 1984). Herpes simplex virus type-1 (HSV-1) is attractive as a vector system, especially for use in the nervous system because of its neurotropic property (Geller and Federoff. 1991; Glorioso,

et al. 1995). Vaccinia virus, of the poxvirus family, has also been developed as an expression vector (Smith and Moss, 1983; Moss, 1992). Each of the above-described vectors are widely available to one skilled in the art and would be suitable for use in the present invention.

5        Retroviral vectors are capable of infecting a large percentage of the target cells and integrating into the cell genome (Miller and Rossmann. 1989). Retroviruses were developed as gene transfer vectors relatively earlier than other viruses, and were first used successfully for gene marking and transducing the cDNA of adenosine deaminase (ADA) into human lymphocytes. Preferred 10      retroviruses include lentiviruses. In preferred embodiments, the retrovirus is selected from the group consisting of HIV, BIV and SIV.

15        “Non-viral” delivery techniques that have been used or proposed for gene therapy include DNA-ligand complexes, adenovirus-ligand-DNA complexes, direct injection of DNA, CaPO<sub>4</sub> precipitation, gene gun techniques, electroporation, liposomes and lipofection (Mulligan, 1993). Any of these 20      methods are widely available to one skilled in the art and would be suitable for use in the present invention. Other suitable methods are available to one skilled in the art, and it is to be understood that the present invention may be accomplished using any of the available methods of transfection. Several such methodologies 25      have been utilized by those skilled in the art with varying success (Mulligan, R. 1993). Lipofection may be accomplished by encapsulating an isolated DNA molecule within a liposomal particle and contacting the liposomal particle with the cell membrane of the target cell. Liposomes are self-assembling, colloidal particles in which a lipid bilayer, composed of amphiphilic molecules such as phosphatidyl 30      serine or phosphatidyl choline, encapsulates a portion of the surrounding media such that the lipid bilayer surrounds a hydrophilic interior. unilamellar or multilamellar liposomes can be constructed such that the interior contains a desired chemical, drug, or, as in the instant invention, an isolated DNA molecule.

30        The cells may be transfected in vivo, ex vivo, or in vitro. The cells may be transfected as primary cells isolated from a patient or a cell line derived from primary cells, and are not necessarily autologous to the patient to whom the cells are ultimately administered. Following ex vivo or in vitro transfection, the cells

may be implanted into a host. Genetic manipulation of primary tumor cells has been described previously (Patel et al. 1994). Genetic modification of the cells may be accomplished using one or more techniques well known in the gene therapy field (Human Gene Therapy. April 1994. Vol. 5, p. 543-563; Mulligan, R.C. 1993).

In order to obtain transcription of the nucleic acid of the present invention within a target cell, a transcriptional regulatory region capable of driving gene expression in the target cell is utilized. The transcriptional regulatory region may comprise a promoter, enhancer, silencer or repressor element and is functionally associated with a nucleic acid of the present invention. Preferably, the transcriptional regulatory region drives high level gene expression in the target cell. Transcriptional regulatory regions suitable for use in the present invention include but are not limited to the human cytomegalovirus (CMV) immediate-early enhancer/promoter, the SV40 early enhancer/promoter, the JC polyomavirus promoter, the albumin promoter, PGK and the  $\alpha$ -actin promoter coupled to the CMV enhancer (Doll, et al. 1996).

The vectors of the present invention may be constructed using standard recombinant techniques widely available to one skilled in the art. Such techniques may be found in common molecular biology references such as *Molecular Cloning: A Laboratory Manual* (Sambrook, et al., 1989, Cold Spring Harbor Laboratory Press), *Gene Expression Technology* (Methods in Enzymology, Vol. 185, edited by D. Goeddel, 1991. Academic Press, San Diego, CA), and *PCR Protocols: A Guide to Methods and Applications* (Innis, et al. 1990. Academic Press, San Diego, CA).

Administration of a nucleic acid of the present invention to a target cell in vivo may be accomplished using any of a variety of techniques well known to those skilled in the art.

The vectors of the present invention may be administered orally, parentally, by inhalation spray, rectally, or topically in dosage unit formulations containing conventional pharmaceutically acceptable carriers, adjuvants, and vehicles. The term parenteral as used herein includes, subcutaneous, intravenous, intramuscular, intrasternal, infusion techniques or intraperitoneally. Suppositories for rectal

administration of the drug can be prepared by mixing the drug with a suitable non-irritating excipient such as cocoa butter and polyethylene glycols that are solid at ordinary temperatures but liquid at the rectal temperature and will therefore melt in the rectum and release the drug.

5        The dosage regimen for treating a disorder or a disease with the vectors of this invention and/or compositions of this invention is based on a variety of factors, including the type of disease, the age, weight, sex, medical condition of the patient, the severity of the condition, the route of administration, and the particular compound employed. Thus, the dosage regimen may vary widely, but  
10      can be determined routinely using standard methods.

15      The pharmaceutically active compounds (i.e., vectors) of this invention can be processed in accordance with conventional methods of pharmacy to produce medicinal agents for administration to patients, including humans and other mammals. For oral administration, the pharmaceutical composition may be in the form of, for example, a capsule, a tablet, a suspension, or liquid. The pharmaceutical composition is preferably made in the form of a dosage unit containing a given amount of DNA or viral vector particles (collectively referred to as "vector"). For example, these may contain an amount of vector from about  $10^3$ - $10^{15}$  viral particles, preferably from about  $10^6$ - $10^{12}$  viral particles. A suitable  
20      daily dose for a human or other mammal may vary widely depending on the condition of the patient and other factors, but, once again, can be determined using routine methods. The vector may also be administered by injection as a composition with suitable carriers including saline, dextrose, or water.

25      While the nucleic acids and /or vectors of the invention can be administered as the sole active pharmaceutical agent, they can also be used in combination with one or more vectors of the invention or other agents. When administered as a combination, the therapeutic agents can be formulated as separate compositions that are given at the same time or different times, or the therapeutic agents can be given as a single composition.

30      The polypeptide of the present invention may be employed in combination with a suitable pharmaceutical carrier. Such compositions comprise a therapeutically effective amount of the protein, and a pharmaceutically acceptable

carrier or excipient.. Such a carrier includes but is not limited to saline, buffered saline, dextrose, water, glycerol, ethanol, and combinations thereof. The formulation should suit the mode of administration.

5 The invention also provides a pharmaceutical pack or kit comprising one or more containers filled with one or more of the ingredients of the pharmaceutical compositions of the invention. Associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceuticals or biological products, which notice reflects approval by the agency of manufacture, use or sale for human administration. In addition, 10 the polypeptide of the present invention may be employed on conjunction with other therapeutic compounds.

15 The pharmaceutical compositions may be administered in a convenient manner, such as the transdermal, transmucosal, enteral and parenteral intravenous routes. The amounts and dosage regimens of tRNA synthetase polypeptides administered to a subject will depend on a number of factors, such as the mode of 20 administration, the nature of the condition being treated, the body weight of the subject being treated and the judgment of the prescribing physician. Generally speaking, it is given, for example, in therapeutically effective doses of at least about 10  $\mu$ g/kg body weight and, in most cases, it would be administered in an amount not in excess of about 8 mg/kg body weight per day and preferably the dosage is from about 10  $\mu$ g/kg body weight to about 1 mg/kg body weight daily, taking into the account the routes of administration, symptoms, etc.

25 The present invention is further directed to inhibiting tRNA synthetase polypeptides in vivo by the use of antisense technology. Antisense technology can be used to control gene expression through triple-helix formation or antisense DNA or RNA, both of which methods are based on binding of a polynucleotide to DNA or RNA. For example, the 5' coding portion of the mature polynucleotide sequence, which encodes for the polypeptide of the present invention, is used to 30 design an antisense RNA oligonucleotide of from 10 to 40 base pairs in length. A DNA oligonucleotide is designed to be complementary to a region of the gene involved in transcription (triple helix--see Lee et al, Nucl. Acids Res., 6:3073 (1979); Cooney et al, Science, 241:456 (1988); and Dervan et al, Science, 251:

1360 (1991), thereby preventing transcription and the production of VEGF2. The antisense RNA oligonucleotide hybridizes to the mRNA in vivo and blocks translation of an mRNA molecule into the tRNA synthetase polypeptides (antisense--Okano, J. Neurochem., 56:560 (1991); Oligodeoxynucleotides as Antisense Inhibitors of Gene Expression, CRC Press, Boca Raton, Fla. (1988)).

5           Alternatively, the oligonucleotides described above can be delivered to cells by procedures in the art such that the anti-sense RNA or DNA may be expressed in vivo to inhibit production of tRNA synthetase polypeptides in the manner described above. Antisense constructs to tRNA synthetase polypeptides, 10 therefore, may inhibit the activity of the tRNA synthetase polypeptides and prevent the further growth or even regress solid tumors, since angiogenesis and neovascularization are essential steps in solid tumor growth. These antisense constructs may also be used to treat rheumatoid arthritis, psoriasis and diabetic retinopathy which are all characterized by abnormal angiogenesis.

15           Alternatively, angiostatic trpRS therapy can be used to oppose the oppose the angiogenic activity of endogenous and exogenous angiogenic factors, including tyrRS polypeptides, and to prevent the further growth or even regress solid tumors, since angiogenesis and neovascularization are essential steps in solid tumor growth. Such therapies can also be used to treat rheumatoid arthritis, 20 psoriasis and diabetic retinopathy which are all characterized by abnormal angiogenesis.

25           The polypeptides, their fragments or other derivatives, or analogs thereof, or cells expressing them can be used as an immunogen to produce antibodies thereto. These antibodies can be, for example, polyclonal or monoclonal antibodies. The present invention also includes chimeric, single chain, and humanized antibodies, as well as Fab fragments, or the product of an Fab expression library. Various procedures known in the art may be used for the production of such antibodies and fragments.

30           Antibodies generated against the polypeptide corresponding to a sequence of the present invention can be obtained by direct injection of the polypeptide into an animal or by administering the polypeptide to an animal, preferably a nonhuman. The antibody so obtained will then bind the polypeptide itself. In this

manner, even a sequence encoding only a fragment of the polypeptide can be used to generate antibodies binding the whole native polypeptide. Such antibodies can then be used to isolate the polypeptide from tissue expressing that polypeptide.

For preparation of monoclonal antibodies, any technique which provides 5 antibodies produced by continuous cell line cultures can be used. Examples include the hybridoma technique (Kohler and Milstein, 1975, *Nature*, 256:495-497), the trioma technique, the human B-cell hybridoma technique (Kozbor et al., 1983, *Immunology Today* 4:72), and the EBV-hybridoma technique to produce 10 human monoclonal antibodies (Cole, et al., 1985, in *Monoclonal Antibodies and Cancer Therapy*, Alan R. Liss, Inc., pp. 77-96).

Techniques described for the production of single chain antibodies (U.S. Pat. No. 4,946,778) can be adapted to produce single chain antibodies to 15 immunogenic polypeptide products of this invention.

Neutralization antibodies can be identified and applied to mask the activity 20 of tRNA synthetase polypeptides. The utility of such an approach has been shown in mice model systems against VEGF. VEGF2 can also be inactivated by certain dominant negative mutants within the gene itself. It is known that both PDGF.alpha. and .beta. form either heterodimers or homodimers, and VEGF forms homodimers. These antibodies therefore may be used to block endogenous 25 angiogenic activity and retard the growth of solid tumors. These antibodies may also be used to treat inflammation caused by the increased vascular permeability.

These antibodies may further be used in an immunoassay to detect the presence of tumors in certain individuals. Enzyme immunoassay can be 30 performed from the blood sample of an individual.

The present invention is also directed to antagonist/inhibitors of the 35 polypeptides of the present invention. The antagonist/inhibitors are those which inhibit or eliminate the function of the polypeptide. Thus, for example, antagonists bind to a polypeptide of the present invention and inhibit or eliminate its function. The antagonist, for example, could be an antibody against the 40 polypeptide which binds to the polypeptide or, in some cases, an oligonucleotide. An example of an inhibitor is a small molecule which binds to and occupies the 45 catalytic site of the polypeptide thereby making the catalytic site inaccessible to

substrate such that normal biological activity is prevented. Examples of small molecules include but are not limited to small peptides or peptide-like molecules.

Alternatively, antagonists to the polypeptides of the present invention may be employed which bind to the receptors to which a polypeptide of the present invention normally binds. The antagonists may be closely related proteins such that they recognize and bind to the receptor sites of the natural protein, however, they are inactive forms of the natural protein and thereby prevent the action of the normal polypeptide ligand. The antagonist/inhibitors may be used therapeutically as an anti-tumor drug by occupying the receptor sites of tumors. The antagonist/inhibitors may also be used to prevent inflammation. The antagonist/inhibitors may also be used to treat solid tumor growth, diabetic retinopathy, psoriasis and rheumatoid arthritis. The antagonist/inhibitors may be employed in a composition with a pharmaceutically acceptable carrier, e.g., as hereinabove described.

These and other aspects of the present invention should be apparent to those skilled in the art from the teachings herein.

Also preferred is a method for diagnosing in a subject a pathological condition associated with abnormal structure or expression of a gene, which method comprises a step of detecting in a biological sample obtained from said subject nucleic acid molecules, if any, comprising a nucleotide sequence that is at least 95% identical to a sequence of at least 50 contiguous nucleotides in a sequence selected from SEQ ID NO:9

The method for diagnosing a pathological condition can comprise a step of detecting nucleic acid molecules comprising a nucleotide sequence in a panel of at least two nucleotide sequences, wherein at least one sequence in said panel is at least 95% identical to a sequence of at least 50 contiguous nucleotides in a SEQ ID NO:9.

Also preferred is a composition of matter comprising isolated nucleic acid molecules wherein the nucleotide sequences of said nucleic acid molecules comprise a panel of at least two nucleotide sequences, wherein at least one sequence in said panel is at least 95% identical to a sequence of at least 50

contiguous nucleotides SEQ ID NO:9. The nucleic acid molecules can comprise DNA molecules or RNA molecules.

Further preferred is a method for detecting in a biological sample a polypeptide comprising an amino acid sequence which is at least 90% identical to a sequence of at least 10 contiguous amino acids in a sequence selected from the group consisting of amino acid sequences of SEQ ID NO:9, which method comprises a step of comparing an amino acid sequence of at least one polypeptide molecule in said sample with a sequence selected from said group and determining whether the sequence of said polypeptide molecule in said sample is at least 90% identical to said sequence of at least 10 contiguous amino acids of SEQ ID NO:9.

Also preferred is the above method for identifying the species, tissue or cell type of a biological sample, which method comprises a step of detecting polypeptide molecules comprising an amino acid sequence in a panel of at least two amino acid sequences, wherein at least one sequence in said panel is at least 90% identical to a sequence of at least 10 contiguous amino acids in a sequence selected from the above group.

Also preferred is a method for diagnosing in a subject a pathological condition associated with abnormal structure or expression of a gene, which method comprises a step of detecting in a biological sample obtained from said subject polypeptide molecules comprising an amino acid sequence in a panel of at least two amino acid sequences, wherein at least one sequence in said panel is at least 90% identical to a sequence of at least 10 contiguous amino acids of SEQ ID NO:9

The present invention also includes a diagnostic system, preferably in kit form, for assaying for the presence of the polypeptide of the present invention in a body sample, such brain tissue, cell suspensions or tissue sections; or a body fluid sample, such as CSF, blood, plasma or serum, where it is desirable to detect the presence, and preferably the amount, of the polypeptide of this invention in the sample according to the diagnostic methods described herein.

In a related embodiment, a nucleic acid molecule can be used as a probe (i.e., an oligonucleotide) to detect the presence of a polynucleotide of the present

invention, a gene corresponding to a polynucleotide of the present invention, or a mRNA in a cell that is diagnostic for the presence or expression of a polypeptide of the present invention in the cell. The nucleic acid molecule probes can be of a variety of lengths from at least about 10, suitably about 10 to about 5000  
5 nucleotides long, although they will typically be about 20 to 500 nucleotides in length. Hybridization methods are extremely well known in the art and will not be described further here.

In a related embodiment, detection of genes corresponding to the polynucleotides of the present invention can be conducted by primer extension  
10 reactions such as the polymerase chain reaction (PCR). To that end, PCR primers are utilized in pairs, as is well known, based on the nucleotide sequence of the gene to be detected. Preferably, the nucleotide sequence is a portion of the nucleotide sequence of a polynucleotide of the present invention. Particularly preferred PCR primers can be derived from any portion of a DNA sequence  
15 encoding a polypeptide of the present invention, but are preferentially from regions which are not conserved in other cellular proteins.

Preferred PCR primer pairs useful for detecting the genes corresponding to the polynucleotides of the present invention and expression of these genes are described in the Examples, including the corresponding Tables. Nucleotide primers from the corresponding region of the polypeptides of the present invention described herein are readily prepared and used as PCR primers for detection of the presence or expression of the corresponding gene in any of a variety of tissues.

The present invention also provides a screening assay for antiangiogenic compounds. As disclosed herein, antiangiogenic compounds, such as trpRS  
25 polypeptides, can be detected by their ability to oppose the angiogenic effects of tyrRS polypeptides on model systems such as chick allantoic membrane (CAM), and corneal vascularization models.

The diagnostic system includes, in an amount sufficient to perform at least  
30 one assay, a subject polypeptide of the present invention, a subject antibody or monoclonal antibody, and/or a subject nucleic acid molecule probe of the present invention, as a separately packaged reagent.

In another embodiment, a diagnostic system, preferably in kit form, is contemplated for assaying for the presence of the polypeptide of the present invention or an antibody immunoreactive with the polypeptide of the present invention in a body fluid sample. Such diagnostic kit would be useful for monitoring the fate of a therapeutically administered polypeptide of the present invention or an antibody immunoreactive with the polypeptide of the present invention. The system includes, in an amount sufficient for at least one assay, a polypeptide of the present invention and/or a subject antibody as a separately packaged immunochemical reagent.

Instructions for use of the packaged reagent(s) are also typically included.

A diagnostic system of the present invention preferably also includes a label or indicating means capable of signaling the formation of an immunocomplex containing a polypeptide or antibody molecule of the present invention.

The labeling means can be a fluorescent labeling agent that chemically binds to antibodies or antigens without denaturing them to form a fluorochrome (dye) that is a useful immunofluorescent tracer. Suitable fluorescent labeling agents are fluorochromes such as fluorescein isocyanate (FIC), fluorescein isothiocyanate (FITC), 5-dimethylamine-1-naphthalenesulfonyl chloride (DANSC), tetramethylrhodamine isothiocyanate (TRITC), lissamine, rhodamine 8200 sulphonyl chloride (RB 200 SC) and the like. A description of immunofluorescence analysis techniques is found in DeLuca, "Immunofluorescence Analysis", in *Antibody As a Tool*, Marchalonis et al., Eds., John Wiley & Sons, Ltd., pp. 189-231 (1982), which is incorporated herein by reference. Other suitable labeling agents are known to those skilled in the art.

In preferred embodiments, the indicating group is an enzyme, such as horseradish peroxidase (HRP), glucose oxidase, or the like. In such cases where the principal indicating group is an enzyme such as HRP or glucose oxidase, additional reagents are required to visualize the fact that a receptor-ligand complex (immunoreactant) has formed. Such additional reagents for HRP include hydrogen peroxide and an oxidation dye precursor such as diaminobenzidine. An additional reagent useful with glucose oxidase is 2,2'-amino-di-(3-ethyl-benzthiazoline-G-sulfonic acid) (ABTS).

Radioactive elements are also useful labeling agents and are used illustratively herein. An exemplary radio labeling agent is a radioactive element that produces gamma ray emissions. Elements which themselves emit gamma rays, such as <sup>124</sup>I, <sup>125</sup>I, <sup>128</sup>I, <sup>132</sup>I and <sup>51</sup>Cr represent one class of gamma ray emission-producing radioactive element indicating groups. Particularly preferred is <sup>125</sup>I. Another group of useful labeling means are those elements such as <sup>11</sup>C, <sup>18</sup>F, <sup>15</sup>O and <sup>13</sup>N which themselves emit positrons. The positrons so emitted produce gamma rays upon encounters with electrons present in the animal's body. Also useful is a beta emitter, such <sup>111</sup> indium or <sup>3</sup>H.

The linking of labels or labeling of polypeptides and proteins is well known in the art. For instance, antibody molecules produced by a hybridoma can be labeled by metabolic incorporation of radioisotope-containing amino acids provided as a component in the culture medium (see, e.g., Galfre et al., *Meth. Enzymol.*, 73:3-46 (1981)). The techniques of protein conjugation or coupling through activated functional groups are particularly applicable (see, for example, Aurameas, et al., *Scand. J. Immunol.*, Vol. 8 Suppl. 7:7-23 (1978); Rodwell et al., *Biotech.*, 3:889-894 (1984); and U.S. Pat. No. 4,493,795).

The diagnostic systems can also include, preferably as a separate package, a specific binding agent. Preferably the specific binding agent binds the reagent species when that species is present as part of a complex.

In preferred embodiments, the specific binding agent is labeled. However, when the diagnostic system includes a specific binding agent that is not labeled, the agent is typically used as an amplifying means or reagent. In these embodiments, the labeled specific binding agent is capable of specifically binding the amplifying means when the amplifying means is bound to a reagent species-containing complex.

The diagnostic kits of the present invention can be used in an "ELISA" format to detect the quantity of the polypeptide of the present invention in a sample.

Thus, in some embodiments, a polypeptide of the present invention, an antibody or a monoclonal antibody of the present invention can be affixed to a

solid matrix to form a solid support that comprises a package in the subject diagnostic systems.

A reagent is typically affixed to a solid matrix by adsorption from an aqueous medium, although other modes of affixation applicable to proteins and 5 polypeptides can be used that are well known to those skilled in the art. Exemplary adsorption methods are described herein.

Useful solid matrices are also well known in the art. Such materials are water insoluble and include the cross-linked dextran available under the trademark SEPHADEX from Pharmacia Fine Chemicals (Piscataway, NJ), 10 agarose; polystyrene beads of up to 1 micron ( $\mu\text{m}$ ) to about 5 millimeters (mm) in diameter available from several suppliers (e.g., Abbott Laboratories, Chicago, IL), polyvinyl chloride, polystyrene, cross-linked polyacrylamide, nitrocellulose- or nylon-based webs (sheets, strips or paddles) or tubes, plates or the wells of a micro titer plate, such as those made from polystyrene or polyvinylchloride.

15 The reagent species, labeled specific binding agent, or amplifying reagent of any diagnostic system described herein can be provided in solution, as a liquid dispersion or as a substantially dry powder, e.g., in lyophilized form. Where the indicating means is an enzyme, the enzyme's substrate can also be provided in a separate package of a system. A solid support such as the before-described micro 20 titer plate and one or more buffers can also be included as separately packaged elements in this diagnostic assay system.

The packaging materials discussed herein in relation to diagnostic systems are those customarily utilized in diagnostic systems.

25 The preferred embodiment of the present invention is best understood by referring to the FIGURES and the Examples below. The Examples, which follow, are illustrative of specific embodiments of the invention, and various uses thereof. They are set forth for explanatory purposes only, and are not to be taken as limiting the invention.

## EXAMPLE 1

### Preparation of Endotoxin-Free Recombinant TyrRS and TrpRS

Endotoxin-free recombinant human TyrRS and human TrpRS was prepared as follows. Plasmids encoding full-length TyrRS (528 amino acid residues; 5 Figures 1 and 15), truncated TyrRS (mini TyrRS, residues 1-364 of full-length TyrRS; carboxyl-domain of TyrRS, residues 359-528 of full-length TyrRS), full-length TrpRS (471 amino acid residues), or truncated TrpRS (mini TrpRS, residues 48-471 of full-length TrpRS; supermini TrpRS, residues 71-471 of full-length TrpRS), each also encoding a C-terminal tag of six histidine residues, were 10 introduced into *E. coli* strain BL 21 (DE 3) (Novagen, Madison, WI). Human mature EMAPII, also encoding a C-terminal tag of six histidine residues, was similarly prepared for use in some Examples. Over expression of recombinant TyrRS or TrpRS was induced by treating the cells with isopropyl  $\beta$ -D-thiogalactopyranoside for 4 hours. Cells were then lysed and the proteins from 15 the supernatant purified on His•Bind®nickel affinity columns (Novagen) according to the manufacturer's suggested protocol. Following purification, TrpRS proteins were incubated with phosphate-buffered saline (PBS) containing 1  $\mu$ M ZnSO<sub>4</sub> and then free Zn<sup>2+</sup> was removed (Kisselev et al., 1981, *Eur. J. Biochem.* 120:511-17).

20 Endotoxin was removed from protein samples by phase separation using Triton X-114 (Liu et al., 1997, *Clin. Biochem.* 30:455-63). Protein samples were determined to contain less than 0.01 units of endotoxin per mL using an E-Toxate® gel-clot assay (Sigma, St. Louis, MO). Protein concentration was determined by the Bradford assay (Bio-Rad, Hercules, CA) using bovine serum 25 albumin (BSA) as a standard.

## EXAMPLE 2

### Cytokine Activity of Human TyrRS

Human full-length TyrRS (SEQ ID NO:1), human mini TyrRS (SEQ ID 30 NO:3), human TyrRS carboxyl-terminal domain (SEQ ID NO:5), human EMAP II, and *E. coli* TyrRS were analyzed for cytokine activity in assays examining MP

or PMN chemotaxis, MP production of TNF $\alpha$  or tissue factor, or PMN release of myeloperoxidase.

Cells for the various cytokine assays described were prepared from acid citrate dextrose-treated blood of normal healthy volunteers. Human PMNs were 5 isolated from the blood by centrifugation (700 xg) over Histopaque 1077 and 1119 (Sigma). Fractions containing PMNs were exposed to 0.2% NaCl for 30 seconds to lyse erythrocytes, immediately restored to isotonicity by the addition of 1.6% NaCl, and then centrifuged for 10 minutes. This procedure was repeated 10 twice. Human MPs were isolated by centrifugation on Histopaque 1077 (Sigma). The mononuclear fraction was obtained, washed twice in Hanks' balanced salt solution, resuspended in RPMI-1640 medium (Sigma) containing 10% heat-inactivated fetal bovine serum (Sigma), plated in tissue culture flasks, and 15 incubated in a 6% CO<sub>2</sub> incubator at 37°C for 1-2 hours (Kumagai *et al.*, 1979, *J. Immunol. Methods* 29:17-25). Nonadherent cells were removed by washing the flasks three times with Hanks' balanced salt solution, and adherent cells were harvested by incubation with calcium-magnesium free phosphate-buffered saline 20 containing 2 mM EDTA for 15 minutes at 4°C, followed by extensive washing.

MP chemotaxis assays were performed in a ChemoTX microchemotaxis chamber (Neuro Probe, Gaithersburg, MD) containing polycarbonate filters (5  $\mu$ m pores) with polyvinylpyrrolidone (PVP). MPs were suspended in RPMI-1640 medium containing 1% heat-inactivated fetal bovine serum, and 10<sup>4</sup> cells were added to the upper chamber. Sample proteins (1 nM) were added to the lower compartment of chemotaxis chambers, and the chambers were incubated for 3 hours. After incubation, nonmigrating cells were removed, membranes were 25 fixed in methanol, and migrating cells were visualized with the Hemacolor<sup>TM</sup> stain set (EM Diagnostic Systems, Gibbstown, NJ). Migrating cells were counted in high-power fields (HPFs). Each determination shown in Figure 2 represents the average of nine HPF measurements.

MP TNF $\alpha$  production was examined following incubation of 10<sup>5</sup> MPs with 30 1nM of sample protein for 14 hours. Aliquots of the culture supernatant were then assayed for TNF $\alpha$  production using a TNF $\alpha$  enzyme-linked immunosorbent

assay kit (Sigma). Each determination shown in Figure 2 represents the mean of four measurements from at least three independent experiments.

MP tissue factor production was examined following incubation of  $10^4$  MPs with 1 nM of sample protein for 4 hours. Tissue factor activity was then inferred from measurements of Factor VIIa-dependent Factor Xa formation (Wolfson *et al.*, 1990 *J. Chromatogr.* 503:277-81). Each determination shown in Figure 2 represents the mean of four measurements from at least three independent experiments.

PMN release of myeloperoxidase was examined following incubation of  $3 \times 10^6$  PMNs per mL with 1 nM of sample protein for 60 minutes. The generation of peroxidase was then measured by the reduction of 3,3',5,5'-tetramethylbenzidine (Barker *et al.*, 1982, *FEBS Lett.* 150:419-23). Peroxidase activity is shown in Figure 3 as the percent of total peroxidase activity where 100% peroxidase activity is defined as the activity observed for  $3 \times 10^6$  PMNs following exposure to 10  $\mu$ M phorbol ester for 60 minutes. Each determination shown in Figure 3 represents the mean of four measurements from at least three independent experiments.

PMN chemotaxis assays were performed in a ChemoTX microchemotaxis chamber (described herein). Sample proteins (1 nM) were added to the lower compartment of chemotaxis chambers, and  $10^4$  PMNs were added to the upper compartment. Chambers were incubated for 45 min, and migrating cells were counted in HPFs. Each determination shown in Figure 2 represents the average of nine HPF measurements.

As shown in Figure 2 (white bars), TyrRS carboxyl-terminal domain induced MP migration to an extent comparable with that observed for EMAP II. In contrast, no chemotaxis was observed with full-length TyrRS. The TyrRS carboxyl-terminal domain also stimulated production of TNF $\alpha$  (Figure 2, gray bars) and tissue factor (Figure 3, white bars) in MPs, induced the release of myeloperoxidase in PMNs (Figure 3, gray bars), and induced PMN migration (Figure 4). The induction of PMN migration by the TyrRS carboxyl-terminal domain and EMAP II showed the bell-shaped concentration dependence that is characteristic of chemotactic cytokines (Wakasugi *et al.*, *supra*). Full-length

TyrRS had none of the properties observed for the carboxyl-terminal domain (Figures 2-4).

The cytokine activity of the amino-terminal catalytic domain of TyrRS (mini TyrRS) examined in parallel with that of the TyrRS carboxyl-terminal domain. Mini TyrRS did not induce MP migration (Figure 2, white bars) and did not stimulate production of TNF $\alpha$  (Figure 2, gray bars) or tissue factor (Figure 3, white bars) in MPs. Surprisingly, mini TyrRS did induce PMN migration (Figure 4), and this activity showed a bell-shaped concentration dependence. These results suggest that mini TyrRS is a leukocyte chemoattractant. The PMN response to mini TyrRS added to the lower compartment of a chemotaxis chamber was attenuated by the addition of mini TyrRS to the upper well, indicating that enhanced PMN migration was due to chemotaxis, not simply chemokinesis (stimulated random movement). *E. coli* TyrRS, which is similar in size to human mini TyrRS, was inactive in all of the assays (Figures 2-4).

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### EXAMPLE 3

#### Secretion of Human TyrRS From U-937 Cells

In order to examine whether human TyrRS, like human EMAP II, is secreted from apoptotic tumor cells, human histiocytic lymphoma U-937 cells were first grown in serum-free medium to induce apoptosis. Prior to growth in serum-free medium, U-937 cells were maintained in RPMI-1640 medium containing 10% heat-treated FBS (Sigma), 100 U/mL penicillin and 100  $\mu$ g/mL streptomycin (Sigma) in an atmosphere of 6% CO<sub>2</sub> in air at 37°C. U-937 cells were maintained in logarithmic growth phase by routine passage every 2-3 days. For serum-free growth, 4 x 10<sup>6</sup> U-937 cells were cultured in RPMI-1640 medium without FBS for 24 hours. Apoptosis of U-937 cells was verified by DNA fragment assay, in which the characteristic DNA ladder for apoptotic cells was observed on an agarose gel.

30 Cell supernatants were collected following growth of U-937 cells in serum-free media for 4, 12, or 24 hours. These supernatants were then examined by Western blot analysis using a rabbit polyclonal anti-TyrRS antibody. To examine proteins in the cell supernatant, 20 mL of spent culture medium was first treated

with 2 mM PMSF, 10 µg/mL aprotinin, 20 µg/mL leupeptin, and 10 µg/mL pepstatin A. Treated culture medium was concentrated using Centriprep-10 columns (Amicon, Beverly, MA) and then separated on a 12.5% SDS-polyacrylamide gel. Following transfer onto an Immobilon-P™ membrane (Millipore, Bedford, MA), blots were blocked with PBS and 3% BSA and incubated with rabbit polyclonal anti-TyrRS antibodies. After washing, blots were incubated with a 1:4000 dilution of horseradish peroxidase-linked anti-rabbit IgG (Amersham Life Science, Arlington Heights, IL) for detection of TyrRS.

Cell lysates were prepared by first washing collected U-937 cells twice with ice-cold PBS and then resuspending the cells in lysis buffer containing 25 mM HEPES (pH 7.5), 5 mM EDTA, 5 mM dithiothreitol, 0.1% CHAPS, 2 mM phenylmethylsulfonyl fluoride (PMSF), 10 µg/mL aprotinin, 20 µg/mL leupeptin, and 10 µg/mL pepstatin A. Cells were then frozen and thawed three times in liquid nitrogen and centrifuged for 30 minutes at 4°C.

Protein immunoblot analysis of the cell supernatant fraction, with a polyclonal antibody to human TyrRS, revealed that full-length TyrRS was secreted from apoptotic tumor cells, but not from cells under normal conditions (Figure 7A). Under apoptotic conditions, the amount of secreted human full-length TyrRS increased with the incubation time (Figure 7B). After 24 hours of growth in serum-free medium, more than 50% of the total native TyrRS was released from the cells. A similar proportion of mature EMAP II is secreted from U-937 cells under the same conditions (Kao, *et al.*, 1994, *J. Biol. Chem.* 269:25106-19).

To exclude the possibility that the apparent secretion of TyrRS was due to cell lysis, the activity of cytosolic lactate dehydrogenase (LDH) in the supernatants was measured. LDH activities were determined spectrophotometrically with a CytoTox 96 Non-Radioactive Cytotoxicity Assay kit (Promega, Madison, WI). LDH activity in the supernatants was less than 10% of that in cell extracts and did not increase even after 72 hours of incubation. These results are consistent with the hypothesis that the increase of TyrRS in the supernatants is due to protein secretion.

The permeability of the “secreting” apoptotic cells was also examined using Trypan Blue exclusion as a test for intact cells. The apoptotic cells did not take up the stain, indicating that cell lysis was not responsible for the appearance of TyrRS in the apoptotic cell supernatant. As a further control, human alanyl-tRNA synthetase(AlaRS), which possesses none of the cytokine-like motifs of human TyrRS, was examined for possible secretion. Protein immunoblot analysis showed that, under the same apoptotic conditions, no AlaRS was secreted. The activities of four other aminoacyl-tRNA synthetases in the supernatants or cell extracts of apoptotic U-937 cells were also studied. When cell extracts were used in assays with bovine tRNA, aminoacylation was observed only for alanine, isoleucine, lysine, valine, and tyrosine. In contrast, when supernatants were used, only tyrosine was aminoacylated.

#### EXAMPLE 4

##### Cleavage of Human TyrRS by PMN Elastase

In order to examine whether full-length TyrRS can be cleaved by PMN elastase, a protease released from PMNs (Wright, *et al.*, 1992, *J. Cell. Biochem.* 48:344-55), full-length TyrRS was treated with PMN elastase in PBS (pH 7.4) at a protease:protein ratio of 1:3000 for 30 minutes at 37°C. Following cleavage, the sample was separated on a 12.5% SDS-polyacrylamide gel along with untreated human full-length TyrRS, human mini TyrRS, the human TyrRS carboxyl-terminal domain, and a human extended TyrRS carboxyl-terminal domain. Immunoblot analysis was performed as described in Example 3.

As shown in Figure 8A, the addition of PMN elastase to full-length TyrRS generated a doublet of ~40 kD fragments and a ~24 kD fragment. The ~40 kD fragments have a molecular weight similar to that of mini TyrRS. Sequence analysis of the ~40 kD fragments revealed that each has an amino-terminal sequence of M-G-D-A-P(SEQ ID NO: 56), as does human full-length TyrRS. Figure 8B illustrates the local sequence comparison between human pro-EMAP II and human full-length TyrRS in the regions near their cleavage sites.

Immunoblot analysis further revealed that the ~24 kD fragment is a carboxyl-terminal domain. A recombinant extended TyrRS carboxyl-terminal domain (residues 344-528 of human full-length TyrRS) was prepared to more closely reproduce the putative cleavagesite recognized by PMN elastase. Both 5 the extended TyrRS carboxyl-terminal domain and the PMN elastase ~24 kD cleavage product migrated to similar positions on an SDS-polyacrylamide gel (Figure 8A). Subsequent experiments demonstrated that the extended carboxyl-terminal domain was capable of inducing both MP and PMN chemotaxis. In experiments examining the ability of a recombinant truncated 10 mini TyrRS (comprising residues 1-344 of human full-length TyrRS in comparison to mini TyrRS which comprises TyrRS residues 1-364) to act as a chemoattractant, the truncated mini TyrRS was capable of functioning as a chemoattractant for PMNs but not for MPs.

15 *In vivo* cleavage analysis was performed in IL-8-stimulated PMNs, which release PMN elastase (Bjørnland *et al.*, 1998, *Int. J. Oncol.* 12:535-40). Recombinant human full-length TyrRS, when added to such cells, was cleaved into ~40 kD and ~24 kD fragments. When full-length TyrRS was added to nonstimulated PMNs, no TyrRS cleavage was observed. Immunoblot analysis, 20 using antibodies specific for the amino-terminal and carboxyl-terminal domains indicated that the ~40 kD and ~24 kD fragments comprised mini TyrRS and the TyrRS carboxyl-terminal domain, respectively. When native TyrRS, which was isolated from apoptotic U-937 cells, was added to IL-8-stimulated PMNs, the same ~40 kD and ~24 kD fragments were generated.

25 The demonstration that human full-length TyrRS can be split into two distinct cytokines, suggests that there is a link between protein synthesis and signal transduction. In principle, the secretion of an essential component of the translational apparatus as an early event in apoptosis would be expected to arrest translation and thereby accelerate apoptosis. The secreted TyrRS cytokines could function as intercellular signal transducers, attracting PMNs 30 and thus amplifying the local concentration of PMN elastase. This recursive cycle could enhance cleavage of secreted human TyrRS, thereby enhancing

recruitment of macrophages to sites of apoptosis, which would promote removal of cell corpses.

#### EXAMPLE 5

##### Induction of Endothelial Cell Migration by Human TyrRS

5 All  $\alpha$ -chemokines containing the ELR motif, such as IL-8, act as angiogenic factors (Strieter *et al.*, 1995, *J. Biol. Chem.* 270:27348-57). In contrast,  $\alpha$ -chemokines lacking the ELR motif act as angiostatic factors (*id.*). In order to evaluate the angiogenic activity of TyrRS, which contains the ELR 10 motif, human full-length TyrRS and human mini TyrRS were first examined for their ability to induce endothelial cell migration. Such angiogenic assays were performed using human umbilical vein endothelial cells (HUVECs) 15 (Clonetics, Walkersville, MD). Cells were maintained in EGM-2® BulletKit® medium (Clonetics) in an atmosphere of 6% CO<sub>2</sub> at 37°C according to the supplier's instructions.

Cell migration assays were performed using the modified Boyden chamber (6.5 mm Transwells) with polycarbonate membranes (8.0  $\mu$ m pore size) (Costar Corp., Cambridge, MA) (Masood *et al.*, 1999, *Blood* 93:1038-44). Wells were coated overnight with 25  $\mu$ g/mL human fibronectin 20 (Biosource International, Camarillo, CA) in PBS and then allowed to air-dry. HUVECs were suspended in Dulbecco's modified Eagle's medium (DMEM) (Gibco-BRL, Gaithersburg, MD) containing 0.1% BSA (Sigma) and 2 x 10<sup>5</sup> cells per well were added to the upper chamber. The chemotactic stimulus (50 nM of a given TyrRS molecule or 0.5 nM of human vascular endothelial 25 growth factor-165 (VEGF<sub>165</sub>) (Biosource International, Camarillo, CA)) was placed in the lower chamber, and the cells were allowed to migrate for 6 hours at 37°C in a 6% CO<sub>2</sub> incubator. After incubation, non-migrant cells were removed from the upper face of the Transwell membrane with a cotton swab 30 and migrant cells, those attached to the lower face, were fixed in methanol and visualized with the Hemacolor® stain set (EM Diagnostic Systems, Gibbstown, NJ). Migrating cells were counted in high-power fields (HPFs). HUVECs were suspended in media with the inhibitor for 30 minutes before

placement in the chamber. Each determination shown in Figure 16 represents the average of nine HPF measurements.

As shown in Figure 16, human mini TyrRS stimulated induction of HUVEC chemotaxis as did the positive control VEGF<sub>165</sub>. In contrast, no chemotaxis was observed with human full-length TyrRS or human mini TyrRS mutant (containing ELQ in place of conserved ELR motif). The ability of mini TyrRS to induce directed migration of endothelial cells supported the notion that mini TyrRS also may induce angiogenesis *in vivo*.

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## EXAMPLE 6

### Induction of *in vivo* Angiogenesis by Human TyrRS

*In vivo* angiogenesis assays were conducted in chick chorioallantoic membrane (CAM) (Nicolaou *et al.*, 1998, *Bioorg. Med. Chem.* 6:1185-208). Ten-day-old chick embryos were purchased from McIntyre Poultry (Lakeside, CA) and were incubated at 37°C and 70% humidity. A small hole was made with a small crafts drill (Dremel, Emerson Electric, Racine, WI) directly over the air sac at the end of the egg. The embryos were candled to determine a location to drill a second hole directly over embryonic blood vessels. Negative pressure was applied to the original hole, which resulted in the chorioallantoic membrane (CAM) pulling away from the shell membrane and creating a false air sac. A window was cut in the eggshell over the dropped CAM, exposing the CAM to direct access for experimental manipulation. Cortisone acetate-treated 5 mm filter disks were soaked with a particular protein sample (25 ng of VEGF<sub>165</sub> or 250 ng of a given TyrRS molecule) and the filter disks added directly to the CAMs, which were relatively devoid of preexisting blood vessels. The windows were sealed with sterile tape and incubated at 37°C. At 0, 24, and 48 hours following incubation, 3 µg of interferon-alpha inducible protein (IP-10) (R & D Systems, Minneapolis, MN) was topically applied to the filter disks. After 72 hours, the CAM tissue associated with the filter disk was harvested and quantified using a stereo microscope. Angiogenesis was assessed as the number of visible blood vessel branch points within the defined

area of the filter disks. Each determination shown in Figure 17 represents the mean from 5-8 embryos.

As shown in Figure 17, human mini TyrRS induced angiogenesis as did the positive control human VEGF<sub>165</sub>. Moreover, the angiogenesis stimulated by both mini TyrRS and VEGF<sub>165</sub> was inhibited by the angiostatic  $\alpha$ -chemokine, IP-10. Human mini TyrRS mutant failed to induce *in vivo* angiogenesis, suggesting that the ELR motif of mini TyrRS is as important for angiogenesis as the motif is for the angiogenic activity of  $\alpha$ -chemokines.

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## EXAMPLE 7

### Angiostatic Effect of Human TrpRS on Cell Proliferation

Expression of mini TrpRS in human cells is highly stimulated by the addition of interferon- $\gamma$  (IFN- $\gamma$ ) (Shaw *et al.*, 1999, *Electrophoresis* 20:984-93). Expression of the  $\alpha$ -chemokines IP-10 (interferon- $\gamma$  inducible protein) and MIG (monokine induced by interferon- $\gamma$ ) has also been shown to be enhanced by IFN- $\gamma$  (Kaplan *et al.*, 1987, *J. Exp. Med.* 166:1098-108; Farber, 1993, *Biochem. Biophys. Res. Commun.* 192:223-30). These  $\alpha$ -chemokines lack the ELR motif and function as angiostatic factors both *in vitro* and *in vivo* (Strieter *et al.*, *supra*). The presence in mammalian TrpRS molecules of a Rossmann nucleotide binding fold and DLT sequence, in place of the ELR motif, suggests that mammalian TrpRS molecules may function as angiostatic factors.

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The angiostatic activity of TrpRS was first evaluated in experiments testing the ability of human full-length TrpRS and human mini TrpRS to inhibit human VEGF<sub>165</sub>-induced cell proliferation. Tissue culture-treated 96-well plates (Corning Costar Corp., Cambridge, MA) were coated with 0.1% gelatin (Sigma) overnight. Cells were then seeded in the gelatinized plates at a density of  $5 \times 10^3$  cells per well in DMEM medium (Gibco-BRL) containing heat-inactivated fetal bovine serum (FBS) (10%, Sigma) and penicillin/streptomycin (100 units/mL-100  $\mu$ g/mL, Sigma). The following day, the cells were treated with 2  $\mu$ M of a given TrpRS in the presence of 2 nM VEGF<sub>165</sub>. After 72 hours of incubation, assays were performed by using

the CellTiter 96® aqueous one-solution cell proliferation assay kit (Promega, Madison, WI). Results of the inhibition assay are shown in Figure 18 as the percentage of net proliferation of VEGF<sub>165</sub>. Each determination shown represents the mean of five experiments.

5 As shown in Figure 18, human full-length TrpRS exhibited no angiostatic activity and human mini TrpRS was able to inhibit human VEGF<sub>165</sub>-induced cell proliferation.

#### EXAMPLE 8

##### Angiostatic Effect of Human TrpRS on Endothelial Cell Migration

10 The angiostatic activity of TrpRS was next evaluated in experiments testing the ability of human full-length TrpRS and human mini TrpRS to inhibit human VEGF<sub>165</sub>-induced or human mini TyrRS-induced cell migration. Cell migration assays were performed as described in Example 5 with full-length TrpRS or mini TrpRS added to VEGF<sub>165</sub>-induced or mini TyrRS-induced HUVEC samples. HUVEC samples were treated with 0.5 nM VEGF<sub>165</sub>, 50 nM mini TyrRS, and 500 nM of a given TrpRS. Four measurements of chemotaxis were done for each protein. Each determination shown in Figure 19 represents the average of nine HPF measurements.

15 20 As shown in Figure 19, human mini TrpRS inhibited human VEGF<sub>165</sub>-induced and human mini TyrRS-induced HUVEC chemotaxis. In contrast, human full-length TrpRS had no effect on VEGF<sub>165</sub>-induced or mini TyrRS-induced HUVEC chemotaxis.

#### 25 EXAMPLE 9

##### Angiostatic Effect of Human TrpRS on *in vivo* Angiogenesis

30 The angiostatic activity of human full-length TrpRS and human mini TrpRS was also analyzed in *in vivo* angiogenesis assays conducted in chick CAM. *In vivo* angiogenesis assays were performed as described in Example 6 with 3 µg of full-length TrpRS or mini TrpRS added to VEGF<sub>165</sub>-induced or mini TyrRS-induced CAM tissue.

As shown in Figure 20, the angiogenic activity of human VEGF<sub>165</sub> and human mini TyrRS was inhibited by human mini TrpRS. Human full-length TrpRS had no observable angiostatic activity.

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#### EXAMPLE 10

##### Secretion of Human TrpRS From U-937 Cells

As shown in Example 3, TyrRS is secreted from apoptotic tumor cells where it can be cleaved by PMN elastase to release mini TyrRS and an EMAP II-like carboxyl-domain. In contrast, several other tRNA synthetases, 10 including AlaRS, LysRS, IleRS, and ValRS, were not found to be secreted under the same conditions.

In order to determine whether TrpRS could be secreted under these 15 conditions, secretion assays using U-937 cells were performed as described in Example 3. Cell supernatants were examined by Western blot analysis using a polyclonal anti-TrpRS antibody.

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As shown in Figure 21, human full-length TrpRS was secreted from apoptotic U-937 cells, but not from U-937 cells maintained under normal (*i.e.*, serum) conditions. It was not possible to determine whether human mini TrpRS was also secreted from apoptotic tumor cells, since the amount of mini TrpRS generated from full-length TrpRS is comparatively small.

#### EXAMPLE 11

##### Cleavage of Human TrpRS by PMN Elastase

Cleavage of human full-length TrpRS by PMN elastase was examined 25 using the procedures similar to those described in Example 4. TrpRS was treated with PMN elastase in PBS (pH 7.4) at a protease:protein ratio of 1:3000 for 0, 15, 30, or 60 minutes. Following cleavage, samples were analyzed on 12.5% SDS-polyacrylamide gels. As shown in Figure 22, PMN elastase cleavage of the 54kDa full-length TrpRS generated a major fragment 30 of 47 kDa and a minor fragment of 44 kDa. Both fragments were similar in size to the 49 kDa mini TrpRS fragment.

Western blot analysis with antibodies directed against the carboxyl-terminal His<sub>6</sub>-tag of the recombinant TrpRS protein revealed that both fragments possessed the His<sub>6</sub>-tag at their carboxyl-terminus. Thus, only the amino-terminus of two TrpRS fragments has been truncated. The amino-terminal sequences of the TrpRS fragments were determined by Edman degradation using an ABI Model 494 sequencer. Sequencing of these fragments showed that the amino-terminal sequences were S-N-H-G-P (SEQ ID NO: 57) and S-A-K-G-I (SEQ ID NO: 58), indicating that the amino-terminal residues of the major and minor TrpRS fragments were located at positions 71 and 94, respectively, of full-length TrpRS.

The angiostatic activity of the major and minor TrpRS fragments was analyzed in HUVEC proliferation, HUVEC migration, and chick CAM in vivo angiogenesis assays (as described in Examples 7-9). Recombinant forms of the major and minor TrpRS fragments were prepared for use in these assays. As shown in Figure 23, the major TrpRS fragment (designated as supermini TrpRS) was capable of inhibiting VEGF<sub>165</sub>-stimulated or human mini TyrRS-stimulated angiogenesis. Supermini TrpRS was also capable of inhibiting HUVEC proliferation and migration. Thus, the major product of PMN elastase digestion of full-length TrpRS has angiostatic activity. In the aforementioned assays angiostatic activity was not noted for the minor TrpRS fragment, but angiostatic activity was indicated in a post-natal mouse retinal angiogenesis model.

#### EXAMPLE 12

##### Human Mini TrpRS Primary Structure

Angiogenic mini TyrRS and angiostatic mini TrpRS and supermini TrpRS have their respective ELR and DLT motifs imbedded in closely similar Rossmann binding fold domains. In previous experiments,  $\alpha$ -chemokines possessing the ELR motif have been shown to act as angiogenic factors and  $\alpha$ -chemokines lacking the ELR motif have been shown to act as angiostatic factors (Strieter *et al.*, *supra*). It appears that the biological balance of angiogenic (ELR) and angiostatic (non-ELR)  $\alpha$ -chemokines regulates

angiogenesis (*id.*). For example, the anti-tumor genic IFN- $\gamma$  induces production of IP-10 and MIG (angiostatic  $\alpha$ -chemokines) and also attenuates the expression of IL-8 (angiogenic  $\alpha$ -chemokine) (Gusella *et al.*, 1993, *J. Immunol.* 151:2725-32). Similarly, in some cell lines TrpRS is highly expressed in the presence of IFN- $\gamma$

Mammalian TrpRS shares some sequence similarity with semaphorin-E and neuropilin-2 (Figures 24 and 25). Neuropilin is a receptor for two unrelated ligands with disparate activities: VEGF<sub>165</sub>, an angiogenic factor, and semaphorins, which are mediators of neuronal guidance (Chen *et al.*, 1998, *Neuron* 21:1273-82; Neufeld *et al.*, 1999, *FASEB J.* 13:9-22). Semaphorin-E is also a ligand for neuropilin-2 and semaphorin has been shown to be capable of blocking the binding of VEGF<sub>165</sub> to neuropilin (Chen *et al.*, *supra*). The sequence similarity of a portion of semaphorin-E to TrpRS suggests that human mini TrpRS and human supermini TrpRS bind neuropilin-2, thereby inhibiting VEGF<sub>165</sub> binding to neuropilin-2. Since the shared sequence similarity between neuropilin-2 and TrpRS is located in the neuropilin-2 c-domain that is required for neuropilin-2 dimerization (Chen *et al.*, *supra*) (Figure 25), human mini TrpRS and human supermini TrpRS may inhibit the dimerization of neuropilin-2.

Mature EMAP II has been reported to be a cytokine with anti-angiogenic properties (Schwarz *et al.*, 1999, *J. Exp. Med.* 190:341-54). The carboxyl-domain of human TyrRS has also been shown to have an EMAP II-like cytokine activity (see Example 2). Angiostatic mini TrpRS may be produced by alternative splicing of the pre-mRNA or, as shown in Example 11, angiostatic supermini TrpRS can be generated by PMN elastase cleavage. PMN elastase has been shown to be present in human colorectal carcinoma with particular enrichment at the tumor-host interface (Bjørnland *et al.*, *supra*). Also, breast and non-small cell lung cancer cells are known to secrete PMN elastase *in vitro* (Yamashita *et al.*, 1996, *Chest* 109:1328-34). Thus, human TyrRS and TrpRS, which are secreted from apoptotic cells, may be cleaved by PMN elastase at the tumor-host interface. The cleaved enzymes can then act as angiogenic and angiostatic factors that regulate tumor invasion.

It should be understood that the foregoing disclosure emphasizes certain specific embodiments of the invention and that all modifications or alternatives equivalent thereto are within the spirit and scope of the invention as set forth in the appended claims.